

#108

Kesterson Program

Kesterson Reservoir 1998 Biological Monitoring

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Contents

Section

1.	Introduction	1-1
	Habitat Description and Vegetation Surveys.....	1-2
	Selenium in Soil and Detritus.....	1-2
	Selenium in Plants.....	1-3
	Invertebrate Selenium	1-5
	Ephemeral Pool Monitoring	1-5
	Bird Nesting and Reproduction.....	1-7
	Wild Bird Blood-Se	1-10
	Nest Box and Telemetry Studies.....	1-12
	Small Mammals	1-12
	Bird Populations.....	1-13
	Nocturnal Surveys	1-14
	References	1-15
2.	Habitat Description and Vegetation Surveys.....	2-1
	Objectives	2-1
	Methods.....	2-1
	Previous Studies.....	2-1
	Soils Analyses	2-2
	Studies During 1998.....	2-3
	Results and Discussion.....	2-4
	1998 Growing Season Conditions.....	2-4
	Average Percent Live Cover–Trisection 1 (refer to Table 2).....	2-4
	Average Percent Live Cover–Trisection 2 (refer to Table 3).....	2-6
	Average Percent Live Cover–Trisection 3 (refer to Table 4).....	2-8
	Total Percent Live Cover by Sampling Season	2-8
	Number of Plant Species Observed Within Sampling Plots.....	2-8
	Conclusions.....	2-11
	Disturbance and Land Use	2-11
	Habitat Types	2-12
	Twinspan Cluster Analyses of Species	2-13
	References	2-15
3.	Selenium in Soil and Detritus	3-1
	Introduction	3-1
	Objectives	3-1
	Methods.....	3-1
	Soil.....	3-1
	Detritus	3-2
	Results.....	3-2

	Soil.....	3-2
	Detritus.....	3-4
	Discussion	3-6
	References	3-8
4.	Selenium in Plants.....	4-1
	Introduction.....	4-1
	Objectives.....	4-1
	Methods.....	4-1
	Results.....	4-2
	Persistent Annuals.....	4-3
	Annual Grass.....	4-8
	Perennial Shrubs	4-9
	Perennial Grass.....	4-9
	Selenium Concentrations in Plants Over Time.....	4-11
	Spatial and Temporal Selenium Concentrations in Plants.....	4-11
	Soil-Plant Selenium Relationships	4-12
	Discussion	4-13
	References	4-14
5.	Selenium in Invertebrates.....	5-1
	Introduction.....	5-1
	Objectives.....	5-1
	Methods.....	5-1
	Invertebrate Collections	5-1
	Selenium Analysis.....	5-2
	Results.....	5-2
	Other Invertebrates.....	5-6
	Temporal and Spatial Selenium Concentrations in Invertebrates	5-6
	Discussion	5-8
	References	5-9
6.	Ephemeral Pool Monitoring	6-1
	Extent of Ponding at Kesterson Reservoir During the 1998 Rainy Season	6-1
	Selenium Monitoring in Ephemeral Pools	6-1
	Methods.....	6-1
	Results.....	6-1
	Relative Index of Exposure to Birds	6-8
	Results.....	6-8
	Discussion	6-9
	References	6-10
7.	Bird Nesting and Reproduction.....	7-1
	Introduction.....	7-1
	Objectives.....	7-1

Methods.....	7-1
Nest Searches.....	7-1
Nest Monitoring.....	7-2
Egg Collections.....	7-2
Embryo Ages.....	7-2
Laboratory Examinations.....	7-3
Results.....	7-3
American Avocet.....	7-7
American Kestrel.....	7-8
Barn Swallow.....	7-8
Barn Owl.....	7-9
Black-necked Stilt.....	7-9
European Starling.....	7-10
Killdeer.....	7-10
Waterfowl.....	7-11
Loggerhead Shrike.....	7-12
Lesser Nighthawk.....	7-12
Other Nests.....	7-12
Discussion.....	7-13
References.....	7-20
 8. Selenium in Wild Birds.....	 8-1
Introduction.....	8-1
Objectives.....	8-1
Study Area.....	8-1
Methods.....	8-2
Field Sampling and Selenium Analysis.....	8-2
Laboratory Analyses.....	8-2
Egg-Se Estimation.....	8-3
Results and Discussion.....	8-3
Capture Frequencies.....	8-3
Comparison of Blood-Se of Species at Kesterson.....	8-7
Calculated Concentrations of Selenium in Eggs.....	8-8
References.....	8-11
 9. Nest Box and Telemetry Study.....	 9-1
Introduction.....	9-1
Methods.....	9-1
Setting Up the Nest Boxes.....	9-1
Nest Box Monitoring.....	9-3
Results.....	9-4
Reproductive Success.....	9-4
Selenium Concentrations.....	9-5
Discussion.....	9-7
References.....	9-9

10.	Small Mammals	10-1
	Introduction.....	10-1
	Objectives.....	10-1
	Methods.....	10-1
	Trapping.....	10-1
	Results.....	10-2
	Mammals Captured.....	10-2
	Measurements.....	10-4
	Selenium Concentrations.....	10-5
	Selenium Concentrations in Small Mammals Over Time.....	10-7
	Spatial and Temporal Selenium Concentrations in Small Mammals.....	10-10
	Discussion.....	10-11
	References.....	10-13

Tables

Section 1

1	Selenium Concentrations in Selected Plants (ppm, dry wt.), Kesterson, 1998.....	1-4
2	Summary of Selenium Concentrations (ppm dry weight) in Invertebrates Collected from Kesterson, 1998.....	1-5
3	Selenium Concentrations of Aquatic Invertebrates (ppm, dry wt.) and Water (ppb) in Ephemeral Pools at Kesterson, 1998: Averaged by Pond.....	1-6
4	Summary of Se Concentrations (ppm dry weight) in Bird Eggs Collected from Kesterson Compared by Species, 1998.....	1-8
5	Fate of Nests Found at Kesterson in 1998.....	1-8
6	Blood-Se Concentrations (ppm dry weight) in Wild Birds Trapped ^a at Kesterson, 1998.....	1-10
7	Frequency of Sightings (percent of total sightings) During Nocturnal Surveys.....	1-14

Section 2

1	Summary of 1998 Vegetation Sampling Program.....	2-3
2	Plants Observed at Kesterson Reservoir in 1998.....	2-5
3	Plants Observed at Kesterson Reservoir in 1998.....	2-7
4	Plants Observed at Kesterson Reservoir in 1998.....	2-9
5	List of Dominant Cover Types by Habitat and Trisection.....	2-10
6	Plant Species Included in All Figures of Vegetation Percent Cover for Dominant Plant Species.....	2-12

Section 3

1	Total and Water-extractable Soil Selenium Concentrations (ppm dry weight.) at Kesterson, 1998.....	3-2
2	Se Concentrations (ppm dry weight) of Soil Selenium from Kesterson Reservoir....	3-3
3	Selenium Concentrations (ppm dry weight) in Detritus Samples, 1998.....	3-4
4	Se Concentrations (ppm, dry wt.) in Detritus Samples, 1988 - 1998.....	3-6

Section 4

1	Summary of Se Concentrations (ppm dry weight) in Plants Collected from Kesterson, 1998	4-3
2	Selenium Concentrations (ppm dry weight) in Alkali Weed, 1998	4-4
3	Selenium Concentrations (ppm dry weight) in Filaree, 1998	4-5
4	Selenium Concentrations (ppm dry weight) in Clover, 1998	4-5
5	Selenium Concentrations (ppm dry weight) in Mustard, 1998	4-6
6	Selenium Concentrations (ppm dry weight) in Bassia, 1998	4-7
7	Selenium Concentrations (ppm dry weight) in Prickly Lettuce, 1998.....	4-7
8	Selenium Concentrations (ppm dry weight) in Annual Grass, 1998.....	4-8
9	Selenium Concentrations (ppm dry weight) in Saltbush, 1998	4-9
10	Selenium Concentrations (ppm dry weight) in Saltgrass, 1998	4-10
11	Selenium Concentrations (ppm dry weight) in Bunchgrass, 1998.....	4-10
12	Se Concentrations (ppm dry weight) in Plants Collected from Kesterson, 1988 - 1998	4-11
13	Summary of Se Concentrations (ppm dry weight) in Collected from Kesterson, 1989 - 1998	4-11

Section 5

1	Summary of Selenium Concentrations (ppm dry weight) in Invertebrates Collected from Kesterson.....	5-2
2	Selenium Concentrations (ppm dry weight) in Beetles, 1998.....	5-3
3	Selenium Concentrations (ppm dry weight) in Crickets, 1998.....	5-4
4	Selenium Concentrations (ppm dry weight) in Grasshoppers, 1998.....	5-5
5	Selenium Concentrations (ppm dry weight) in Spiders, 1998	5-6
6	Selenium Concentrations (ppm dry weight) in Invertebrates Collected from Kesterson, 1988 - 1998	5-7
7	Summary of Selenium Concentrations (ppm dry weight) in Invertebrates Collected from Kesterson Since Filling, 1989 - 1998	5-8

Section 6

1	Geometric Mean Selenium Concentrations in Water and Invetebrates from Kesterson Reservoir Rainwater Pools, 1998	6-2
2	Bioaccumulation Factors for Selenium in Kesterson Reservoir Aquatic Biota Groups, 1998	6-6
3	Average Tissue Se Concentrations in Aquatic Invertebrates from Kesterson, 1983 - 1998	6-12

Section 7

1	Results of Nest Observations and Se Analysis of Eggs, Kesterson 1998.....	7-3
2	Se Concentrations (ppm dry weight) in American Avocet Eggs Collected from Kesterson.....	7-8
3	Se Concentrations (ppm dry weight) in American Kestrel Eggs Collected from Kesterson.....	7-8

4	Se Concentrations (ppm dry weight) in Barn Swallow Eggs Collected from Kesterson	7-9
5	Se Concentrations (ppm dry weight) in Barn Owl Eggs Collected from Kesterson.....	7-9
6	Se Concentrations (ppm dry weight) in Black-necked Stilt Eggs Collected from Kesterson.....	7-9
7	Se Concentrations (ppm dry weight) in European Starling Eggs Collected from Kesterson.....	7-10
8	Se Concentrations (ppm dry weight) in Killdeer Eggs Collected from Kesterson ..	7-11
9	Se Concentrations (ppm dry weight) in Duck Eggs Collected from Kesterson.....	7-11
10	Se Concentrations (ppm dry weight) in Lesser Nighthawk Eggs Collected from Kesterson.....	7-12
11	Summary of Se Concentrations (ppm dry weight) in Bird Eggs Collected from Kesterson Compared by Species, 1998.....	7-13
12	Fate of Nests Found at Kesterson, 1998	7-14
13	Kesterson Eggs Incubated Through the Late Stages of Development at UCD	7-19

Section 8

1	Blood-Se concentrations (ppm dry weight) for birds collected from various locations in California. Number of samples (n), range of blood-Se (Range), and geometric mean selenium concentrations (GM) are shown.	8-4
2	Total selenium concentrations (ppm, dry weight) in potential prey species of predatory birds at Kesterson. Analyses were for whole animals. Sample sizes (n), range of whole-body selenium concentration (Range), and geometric mean selenium concentrations (GM) are shown.....	8-5
3	Summary of Se Concentrations (ppm dry weight) in Predatory Birds Collected from Kesterson, 1994 – 1998	8-8
4	Female parent blood (Blood-Se) during nesting and egg selenium (Egg-Se) concentrations (ppm, dry weight) of American kestrels collected from nest boxes at Kesterson during 1997 and 1998. Egg selenium concentrations calculated from parent blood selenium and the ratio of observed-to-calculated egg selenium are shown for comparison.....	8-9
5	Blood-Se (Se) and date of sampling (Date) in American kestrels, barn owls, and loggerhead shrikes from Kesterson sampled more than once.	8-10

Section 9

1	Reproduction in kestrels and barn owls using nest boxes on and off Kesterson Reservoir, 1998	9-4
2	Selenium Concentrations (ppm dry weight) in Kestrel and Barn Owl Blood and Eggs, 1998	9-5
3	Blood-Se in kestrels and barn owls using nest boxes on and off Kesterson Reservoir, 1998	9-6
4	Telemetry Observations of American Kestrels at Kesterson, 1997 and 1998.....	9-7

Section 10

1	Success and sex ratio of small mammals (California voles, deer mice, western harvest mice, house mice, Heermann's kangaroo rats, and ornate shrews) captured at Kesterson from 1988 to 1998.....	10-3
2	Body weight (g), total length (mm) condition index (CI, [g body weight/ mm body length]), and selenium concentration (ppm, dry wt) in adult small mammals collected, weighed, and measured at Kesterson from 1988 to 1998.	10-4
3	Summary of Se Concentrations (ppm dry weight) in whole-bodiesa of Small Mammals Collected from Kesterson, 1998	10-5
4	Summary of Se Concentrations (ppm dry weight) in Whole-bodiesa of Small Mammals Collected from Kesterson, 1998	10-6
5	Se Concentrations (ppm dry weight) in Ornate Shrews (whole body) Collected from Kesterson Reservoir	10-7
6	Se Concentrations (ppm dry weight) in Deer Mice (whole bodya) Collected from Kesterson Reservoir	10-7
7	Se Concentrations (ppm dry weight) in Western Harvest Mice (whole bodya) Collected from Kesterson Reservoir.....	10-8
8	Se Concentrations (ppm dry weight) in House Mice (whole bodya) Collected from Kesterson Reservoir	10-9
9	Se Concentrations (ppm dry weight) in California Voles (whole bodya) Collected from Kesterson Reservoir	10-10
10	Summary of Se Concentrations (ppm dry weighta) in Small Mammals Collected from Kesterson, 1989 - 1998b	10-10
11	Se Concentrations (ppm dry weight) in Small Mammals (whole bodya) Collected from Kesterson Reservoir	10-11

Figures**Section 1**

1	Kesterson Total Rainfall, 1990 - 1998.....	1-1
2	Seasonal Blood-Se in Birds from Kesterson, 1994 - 1998.....	1-11
3	Selenium Concentrations in Blood of Birds from Kesterson and Other Areas of California, 1994 - 1998.....	1-11

Section 2

1	Twinspan Analysis of Plant Species - 1993.....	2-14
2	Twinspan Analysis of Plant Species - 1998.....	2-14

Section 3

1	Relationship of Total Soil Selenium to Water-extractable (WxSe) Selenium.....	3-3
2	Relationship Between Selenium in Detritus and Total Water-Extractable Soil Selenium	3-5
3	Kesterson Location and Habitats.....	3-7

Section 4

1	Box Plots of Selenium Concentrations Among Trisections (A) and Habitat Types (B). The Bars from the bottom up are the 10th, 25th, 50th, 75th, and 90th percentiles, the circles are outliers.....	4-2
2	Selenium Concentrations in Alkali Weed ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1988 (before filling) - 1998	4-4
3	Selenium Concentrations in Filaree ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1990 - 1998	4-5
4	Selenium Concentrations in Clover ($\bar{x}$, ± 1 SE) Collected at Kesterson, 1994 - 1998	4-6
5	Selenium Concentrations in Bassia ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1988 - 1998	4-7
6	Selenium Concentrations in Prickly Lettuce ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1989 - 1998	4-8
7	Selenium Concentrations in Annual Grass ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1989 - 1998	4-9
8	Selenium Concentrations in Saltgrass ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1988 - 1998	4-10
9	Relationship of Water-extractable Selenium (WxSe) to Plant Groups, 1998	4-12
10	Maximum Selenium Concentration (ppm, dry weight) in Plants from Kesterson, 1988 - 1998	4-13

Section 5

1	Box Plots of Selenium Concentrations in Invertebrates Among Trisections (A) and Habitat Types (B). The Bars from the bottom up are the 10th, 25th, 50th, 75th, and 90th percentiles, the circles are outliers.	5-2
2	Selenium Concentrations in Beetles ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1988 - 1998.	5-3
3	Selenium Concentrations in Crickets ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1988 - 1998	5-4
4	Selenium Concentrations in Grasshoppers ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1988 - 1998	5-5
5	Selenium Concentrations in Spiders ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1988 - 1998	5-6
6	Geometric Mean Selenium Concentration in Invertebrates from Kesterson, 1988 - 1998	5-7

Section 6

4	Invertebrate Tissue Selenium and Water Concentrations, Kesterson Ephemeral Pools, 1998.....	6-3
5	Log Water Selenium Concentration (ug/L)	6-7
6	Dietary Selenium Exposure Index, Kesterson, 1998.....	6-11

Section 7

- 1 Cumulative Probability of Clutch Initiation by Killdeer..... 7-16
- 2 Rainfall (inches) and Killdeer Nests Started from February 1 Through
March 30, 1996–1998 7-17
- 3 Number of Killdeer Observed (Daily Use) During the Breeding Season (February
through June) and Number of Nests Found 7-18

Section 8

- 1 Predicted Egg Selenium in American kestrels (AMKE) Barn Owls (BNOW) and
Loggerhead Shrikes (LOSH)..... 8-8
- 2 Seasonal Blood-Se in Birds from Kesterson, 1994 – 1998..... 8-11

Section 9

- 1 Approximate Locations and Fate of Nests and Nest Boxes on Kesterson, 1998 9-2

Section 10

- 1 Number of Heermann’s kangaroo rats (DIHE), California voles (MICA), house
mice (MUMU), deer mice (PEMA), western harvest mice (REME), and ornate
shrews (SOOR) trapped each year at Kesterson from 1988 to 1998..... 10-4

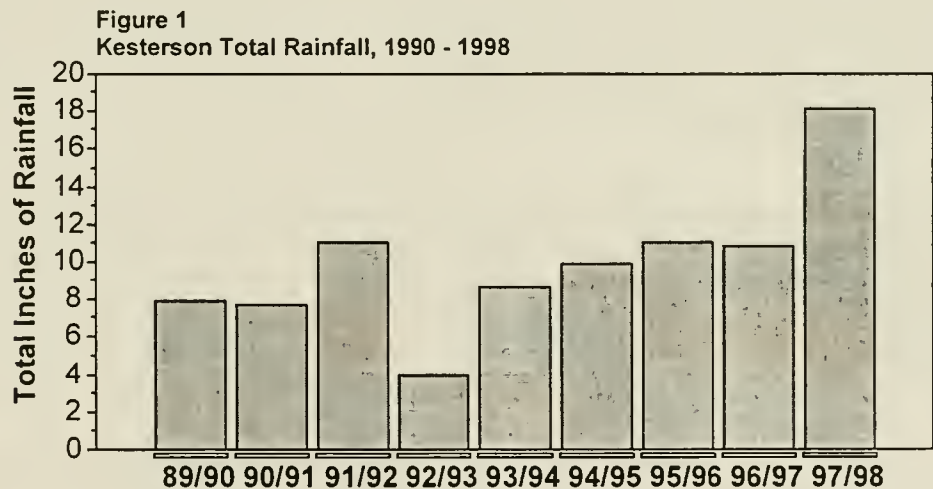
Appendices

- A Kesterson Biomonitoring Program

1. Introduction

In 1995, the U.S. Bureau of Reclamation (Reclamation), Central Valley Regional Water Quality Control Board (RWQCB), U.S. Fish and Wildlife Service (Service), and CH2M HILL changed the monitoring program at Kesterson from annual comprehensive monitoring to more focused annual monitoring of selected biota that were judged to be at the highest risk, with more comprehensive sampling of biota every three years. The current year (1998) was the first year that complete monitoring has been conducted since 1995.

This was an unusually wet year (Figure 1; Water year depicted is from July 1 to June 30) with rainfall and persistent ephemeral pools lasting far into the growing season for plants and the breeding season for birds. This delayed plant growth, timing, and success of nesting at Kesterson as well as other areas of California (A. Erichsen, University of California, Davis; R. Anderson, Swainson's Hawk Technical Action Committee; S. Buranek, National Park Service; personal communication). Also, because much of Kesterson was covered with water during the time that invertebrate and small mammal collections were planned, these tasks were delayed. Biota such as mushrooms were not observed growing in significant numbers because much of Kesterson was flooded. The interior roads have not been maintained and many were not usable until summer, which made many of the surveys and collection more difficult and slower, and some surveys were delayed or could not be conducted.



Following this introduction and summary of 1998 Kesterson monitoring are detailed reports on the following studies:

- Habitat Descriptions and Vegetation Surveys
- Selenium in Soil and Detritus
- Selenium in Plants
- Selenium in Invertebrates
- Ephemeral Pool Monitoring
- Bird Nesting and Reproduction
- Wild Bird Blood-Se

- Nest Box and Telemetry Studies
- Small Mammals

Bird populations surveys and nocturnal wildlife surveys are discussed in the Introduction and Summary and are not discussed in separate sections.

Habitat Description and Vegetation Surveys

The 1998 vegetation studies at the site assessed potential changes in the plant species in terms of presence and cover. The terrestrial wildlife habitat at Kesterson is currently a mixture of alkali desert scrub and native and non-native annual grassland plant communities.

Above-average precipitation fell in late winter and early spring (with 7.7 inches falling in February and 2.05 inches in March). Spring and summer temperatures were cooler than normal, reaching a maximum of 97 degrees Fahrenheit in August. A significant amount of standing water was present at Kesterson (predominantly in the Open habitat and in areas of low topography in Filled habitat types) until late spring. Soils in the Grassland habitat type were extremely saturated even though ponding water was not observed in Grassland sample plots.

Many early-blooming plants such as annual grasses and forbs did not flower or set seed until summer, and late-blooming species (such as *Atriplex* sp.) did not flower until after the last sampling period was conducted in July. Less dead plant cover and thatch was detected in all habitats and trisections in 1998 than in previous years with normal rainfall and temperature. Also, bare ground cover values were higher than 10 percent in all habitat types in all trisections except for Grassland habitat in Trisections 2 and 3. This may be partly attributed to the delayed growth of many plants due to above-average precipitation combined with seasonally cool temperatures.

Results of 1998 vegetation monitoring suggest that the Filled and Open habitat types at Kesterson were influenced by above-normal precipitation and cooler temperatures. The prevalence of wetland species in many plots is suggestive of their positive germination and growth response to these conditions. Vegetation showed a delay in plant germination and growth (as evidenced the large "percent cover" values for bare ground and standing water in all trisections until the August sampling session).

Selenium in Soil and Detritus

The level and distribution of selenium in the soil, especially in the top 15cm of water-extractable soil selenium, relate to contamination found in plants and, therefore available to wildlife that feed on plants (Wahl et al. 1994). This relationship is highly variable although the slope is significant (Ohlendorf and Santolo 1994, Santolo 1994). Selenium concentrations measured in soil vary from year-to-year and among the sampling locations. Some of this variability may be due to vegetation type at the sample location, soil parent type, rainfall prior to sampling, and other factors.

Soil samples were collected at each sample station by inserting a 2.54-cm corer about 15cm into the soil and a 4-cm corer was used to collect soil from 15 to 50cm and from 50-100cm.

Duplicate cores were collected at each site, within a radius of about 1m of the station center. Soil samples were analyzed by Lawrence Berkeley Laboratory (LBL) for total selenium and water-extractable selenium. The extracts used in the total water extractable selenium analysis were made using a 5:1 water to dry-mass ratio following procedures described in previous progress reports by LBL.

Total soil selenium and water-extractable soil selenium from soil collected in 1998 were generally highest in Trisection 1 and in Open habitat types. Selenium concentrations in total soil selenium were significantly higher in Open and Grassland habitats than in Filled habitat samples and concentrations in Open were higher than in Grassland habitats. In the water-extractable fraction, selenium was significantly higher in Open habitats than either Grassland or Filled, which were not statistically different. Water-extractable soil selenium concentrations were strongly correlated to plant selenium in 1998 samples.

The detritus layer (i.e., the layer of organic material on the soil surface) has been associated with high levels of selenium that may pose a risk to animals that either feed on the detritus itself or feed on those animals that live and feed in it. To better characterize that risk, detritus samples have been analyzed for selenium since 1996. Detritus samples are collected from the soil surface at each plant-sampling site.

Detritus samples collected in 1998 (from the same areas as samples collected in 1996 and 1997) tended to be slightly, but not significantly, higher than samples from the two previous years. In 1998, as in other years, detritus samples collected from Open habitat areas were significantly higher than samples collected in Filled and Grassland habitats. Selenium in detritus from Filled and Open habitats (compared within habitat types) were slightly (but not significantly) higher in 1998 than in 1996 and 1997. In Grassland habitats, selenium levels were similar in 1996, 1997, and in 1998, and significantly lower than in samples from 1988.

Selenium in soil and biota from Open habitats is typically higher than in samples from other habitats at Kesterson. As the Open habitat vegetation becomes denser over time and as the cattails left on-site continue to break down and contribute to the detritus layer, this trend will probably continue. Fortunately, Open habitat covers the smallest area of Kesterson (about 13 percent), reducing the potential for exposure to animals foraging at the site.

Selenium in Plants

The level of selenium contamination found in plants and, therefore available to wildlife that feed on plants, was determined by collecting plant samples from at least three growing plants within each of the permanent sample sites. Although selenium concentrations measured in plants vary from year-to-year, no plant selenium levels changed significantly from levels measured in 1995.

The geometric mean selenium concentrations in plants collected in 1998 ranged from 1.2 ppm in perennial bunchgrass to 8.8 ppm in mustard (overall geometric mean for plants = 3.8 ppm, $n = 240$). There were no significant differences found in plant selenium among the species collected.

When plants were analyzed by habitat type (Filled, Grassland, and Open), selenium concentrations in annual grass, clover, and prickly lettuce collected from Open areas were significantly higher than those from either Filled or Grassland habitats (Table 1).

TABLE 1
Selenium Concentrations in Selected Plants (ppm, dry wt.), Kesterson, 1998

Plant and Habitat	<i>n</i>	Geometric Mean ^b	Range
<i>Annual Grass</i>			
Filled	13	2.4	0.5 – 11
Grassland	14	2.3	0.9 – 6.5
Open	17	14.0	2.4 – 6.7
<i>Clover</i>			
Filled	10	2.1	0.5 – 7.1
Grassland	15	2.8	0.7 – 27
Open	9	10.0	2.2 – 24
<i>Prickly Lettuce</i>			
Filled	10	1.4	0.2 – 3.5
Grassland	17	2.8	0.5 – 14
Open	14	11.0	2.7 – 27

The site-wide geometric mean plant selenium level continues to stay slightly below 4.0 ppm, although plant concentrations vary both spatially and (not significantly) by species. The small changes observed for site-wide plant selenium concentrations from year-to-year are generally not significant. However, as in other years, when plant selenium is measured within smaller areas (i.e., by Trisection or Habitat), differences can be found. In most cases, Open habitats continue to support vegetation with higher selenium concentrations than those measured in Filled or Grassland habitats. A mitigating factor is that only a small portion (about 13 percent) of Kesterson is Open habitat.

Guidelines for dietary selenium concentrations were evaluated for birds by the National Irrigation Water Quality Program (NIWQP 1998) based on average daily exposure on a dry weight basis as follows:

No Effect. Less than 3 ppm selenium

Reproductive Impairment. 3 – 8 ppm selenium

Toxicity Threshold. Greater than 10 ppm selenium

The mean selenium concentration in plants falls within the Reproductive Impairment level for dietary exposure to birds. However, most birds that feed at Kesterson feed on a variety of food items over various-sized home ranges and are unlikely to be chronically exposed to food items at the higher range of selenium found in samples. Many animals foraging at Kesterson will likely feed both on- and off-site and among the different trisections and habitats, thereby mitigating their intake of food items with high selenium levels.

Invertebrate Selenium

Invertebrates are important as first- (i.e., herbivores and detritivores) and second- (i.e., carnivores) order consumers that are closely associated with plants. They are also important as food items providing an important source of protein for birds and mammals, especially during the breeding season. The effect of elevated selenium to invertebrates, especially terrestrial invertebrates, is not known and has not been well studied (NIWQP 1998).

Population fluctuations at Kesterson are likely due to factors other than selenium, such as climatic changes and plant succession. Studies at Kesterson have been designed to evaluate invertebrates as an exposure route to vertebrate animals (i.e., birds and mammals).

Selenium concentrations in carnivorous and scavenger species tend to be higher than those in herbivorous species.

The geometric mean selenium concentrations in invertebrates collected in 1998 ranged from 1.8 ppm in grasshoppers to 61 ppm in beetles (Table 2). When beetles were separated into herbivores and carnivores (i.e., predatory and carrion-eating beetles), the carnivorous beetles and spiders had significantly higher geometric mean selenium concentrations than was found in herbivorous beetles and grasshoppers. Beetle (lumped together for comparison to other years) selenium concentrations were not significantly different from other invertebrates in 1998.

TABLE 2

Summary of Selenium Concentrations (ppm dry weight) in Invertebrates Collected from Kesterson, 1998

Species	<i>n</i>	Geometric Mean ^a	Range
Aerial insects ^b	1	7.8	
Beetles	64	17 AB	4.2 - 61
<i>Carnivorous Beetles</i>	44	23 A	5.7 - 61
<i>Herbivorous Beetles</i>	20	9.6 B	4.2 - 36
True Bugs	1	11	
Crickets	4	12 AB	3.9 - 24
Grasshoppers	34	7.2 B	1.8 - 17
Spiders	34	17 A	8.1 - 36
All Invertebrates	139	14	1.8 - 61

^a There was no significant difference in selenium concentrations among species in 1998 (Tukey-Kramer HSD $P \leq 0.05$).

^b These are mixed aerial insects caught in sweep nets and they were not identified.

Ephemeral Pool Monitoring

Extensive rainwater pools formed at Kesterson during the winter of 1998. During previous monitoring years the pools were usually limited to small, well-defined areas of Kesterson. In some years (i.e., 1994) the pools were so limited in duration and extent that no significant aquatic invertebrate populations had time to develop. In contrast, the 1997 - 1998 El Niño winter provided high rainfall to the Kesterson area over an extended period of time. As a result, winter rainwater pools were extensive and persistent for much of the winter and into late spring. The pools varied from a few inches to 2 or 3 feet in depth and temporarily covered large areas of the terrestrial habitats of Kesterson.

The pools started forming at Kesterson during December of 1997 and persisted through June of 1998. The areal extent of ephemeral pools was estimated by ground surveys on March 1 and May 1 and by aerial photographs taken February 24 and April 17, 1998. Various pools were sampled during 6 collection trips conducted between March and June in 1998 for analysis of total selenium in surface water. In addition, several species of aquatic invertebrates were collected from the pools at the time of water collection (from 1 to 4 species per pool) and analyzed for whole-body selenium concentration in samples composited by species. Biota and water samples were collected at least once during the 1998 season from pools in every Pond except Pond 8.

Water samples ranged from 1.0 to 62 ppb total selenium with a geometric mean of 5.6 ppb Se. Aquatic invertebrates collected from the same pools ranged from 2.3 to 94 ppm whole body selenium (dry weight basis) with a mean of 21 ppm selenium. Summary results by Pond are shown in Table 3, below. Selenium contamination in the pools followed a pattern established in previous years at Kesterson. The highest selenium levels were found in water and invertebrates from Ponds 2, 4, 5, and 10 while lower levels were consistently found from the pools of Ponds 6, 7, 9, and 11. Mean selenium concentrations in water boatmen, midge larvae, and micro-crustaceans (*Daphnia* and ostracods) were similar to values from 1997 and previous years. As seen in previous years, some of the highest invertebrate concentrations were found in *Daphnia* populations, particularly from Pond 2. The geometric mean selenium concentration in crustaceans was 32 ppm selenium (dry wt.) as compared to the aquatic insect mean concentration of 19 ppm selenium. These means are both 3 to 4 ppm lower than those found in 1997. The drop in bioaccumulation estimates for 1998 may be due to the greatly enhanced sample coverage (121 invertebrate samples versus 22 in 1997) and/or dilution of the water-borne selenium concentrations by the larger pool sizes in 1998. All 1998 water samples were lower in selenium concentration than the 1997 samples from comparable pools.

TABLE 3

Selenium Concentrations of Aquatic Invertebrates (ppm, dry wt.) and Water (ppb) in Ephemeral Pools at Kesterson, 1998: Averaged by Pond

Pond	Geometric Mean Invertebrate Selenium Concentration (n)	Geometric Mean Pool Selenium Concentration (n)
1	23.7 (20)	3.4 (7)
2	44.2 (15)	27.5 (9)
3	15.7 (7)	6.5 (4)
4	29.3 (11)	5.9 (6)
5	28.9 (15)	6.0 (6)
6	14.9 (8)	3.7 (6)
7	16.5 (4)	5.3 (2)
9	15.8 (15)	3.0 (5)
10	29.2 (13)	5.6 (5)
11	5.3 (12)	1.8 (5)
12	4.3 (1)	2.9 (1)
Overall Means	20.7 (121)	5.6 (56)

Bird Nesting and Reproduction

Bird nest searches were conducted along access roads and interior areas of Kesterson. Eggs were collected and nests were monitored to determine success or failure. In 1998, rainfall was heavier than normal, especially during the breeding season for many of the bird species that use Kesterson. About 13, of the total 18, inches of rainfall at Kesterson in 1998 fell from February through May. Plant, invertebrate, and small mammal sampling indicated that the reproductive season for many species was delayed or interrupted. However, with heavy rain continuing so late in the year, rainwater pools persisted throughout Kesterson and some shorebirds (i.e., black-necked stilts and American avocets) that are not normally observed nesting at Kesterson nested in relatively high numbers (especially stilts), possibly because aquatic invertebrates were abundant in these pools.

One randomly selected egg was collected from each nest found. Eggs were collected early during the incubation period from most nests so that as many nests as possible would be sampled (i.e., few nests were not sampled due to predation of the nest prior to collecting an egg). This provides a representation of selenium concentrations for the entire site and helps to identify possible hot spots for management or additional sampling. However, collecting early during the incubation period may increase the proportion of eggs considered viable (i.e., fertile eggs or those with living embryos), because there is potentially higher embryo mortality later during incubation and embryo teratogenesis is more likely to be found in later-stage embryos.

To address this problem of collecting eggs early enough to avoid losses from predation and also collecting samples that are likely to show embryo mortality or teratogenesis (if it is occurring), two eggs were collected from each shorebird nest (and some other species nests). The second egg was incubated until the embryo was in the last third of development and the embryo was then evaluated for abnormalities. Preliminary results of this study found no abnormalities or increased mortality in embryos from these artificially incubated eggs (Steven Detwiler, UC Davis, personal communication).

Generally, nesting by wetland-associated species was higher than in previous years and nesting by terrestrial species was lower. Although selenium levels in most eggs were elevated above background levels, no seleno-toxic effects were observed in 1998. Geometric mean selenium concentrations were similar among most species collected from Kesterson in 1998 (Table 4). The exception was black-necked stilts that nested at Kesterson because of the persistence of rainwater pools on-site. Overall success of nests that were found at Kesterson in 1998 was 32 percent. Almost half (49 percent) of all the nests found in 1998 were lost to predators and 14 percent were abandoned by the adults (Table 5).

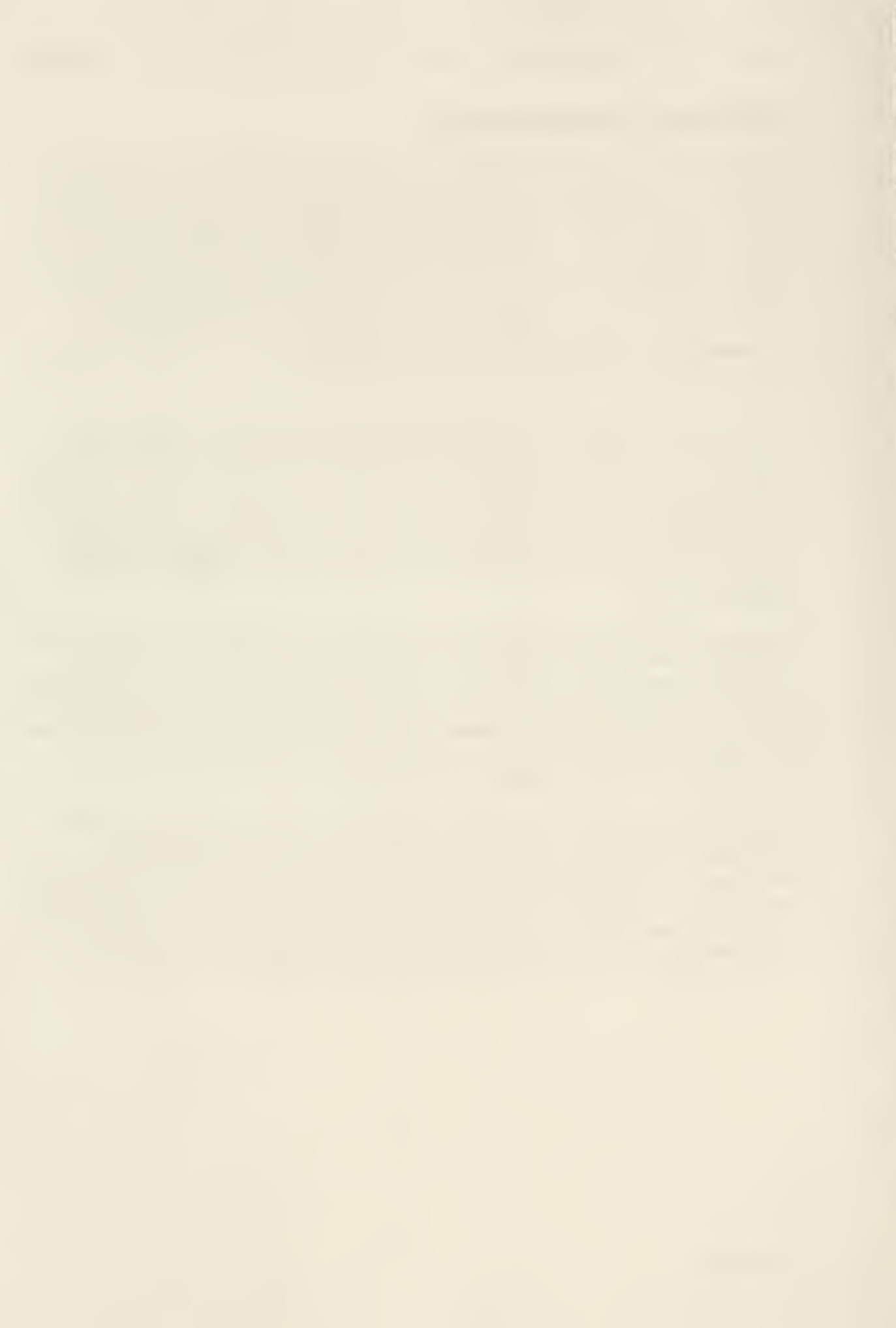


TABLE 4

Summary of Se Concentrations (ppm dry weight) in Bird Eggs Collected from Kesterson Compared by Species, 1998

Species	n	Geometric Mean ^b	Range
American avocet	4	3.7	2.5 - 7.9
American kestrel	7	3.4	2.3 - 5.0
Barn swallow	3	6.6	6.0 - 7.0
Barn owl	6	3.4	2.4 - 6.7
Black-necked stilt	19	12	2.8 - 42
Brewer's Blackbird	1	13	
Duck	5	5.7	3.5 - 11
European Starling	6	6.2	4.8 - 10
Killdeer ^a	41	8.0	1.9 - 31
Lesser nighthawk	2	8.9	6.2 - 12
Northern barrier	1	6.2	
Red-tailed hawk	1	3.9	
Red-winged blackbird	3	6.8	5.5 - 10

^a Only eggs from nests found on Kesterson are included in this table.^b There was no statistically significant difference in Se concentrations among species.**TABLE 5**

Fate of Nests Found at Kesterson in 1998

Species	Nest Fate					Total Nests
	Abandoned	Predation	Total Unsuccessful	Successful	Unknown	
American avocet	1	3	4	0		4
American kestrel	1	1	2	6		8
Barn owl	3	1	4	3		7
Barn swallow				3		3
Black-necked stilt	3	13	16	3	1	20
Brewer's blackbird	2		2	0	2	4
Duck		5	5	1		6
Great horned owl		1	1			1
Killdeer	7	31	39 ^a	12	2	53
Lesser nighthawk			0	2		2
Loggerhead shrike		2	2	2		4
Mourning dove			0	2		2
Northern harrier		1	1	0		1
Red-tailed hawk		1	1	0		1
Red-winged blackbird	1	1	2	6		8
Total nests	18	59	77	40	6	124

^a One killdeer nest unsuccessful due to flooding.

The percentage of killdeer nests found in the interior and west side of Kesterson (33 percent) was about the same as that found in 1997 (30 percent). Eggs collected from interior nests had a higher geometric mean selenium concentration (GM = 12 ppm, $n = 10$, Range = 5.4-19) than those from along the east side of Kesterson near the San Luis Drain (GM = 6.9 ppm, $n = 32$, Range = 1.9-31). The proportion of killdeer observed during the breeding season (February through June) and nests found were roughly proportional to the number of killdeer using Kesterson (about 2 killdeer for each nest), based on daily use surveys during the breeding period. In 1998, the number of killdeer foraging on Kesterson was more than twice as high as other years and the number of killdeer nests on Kesterson was about 1.8 times higher than in other years. Rainwater pools persisted at Kesterson and surrounding areas also remained flooded far into the breeding season, possibly providing increased food resources. Also, the vegetation structure was changed by the wet conditions and by plant succession so there were more areas with short vegetation suitable for killdeer nesting within Kesterson.

Other than killdeer and black-necked stilts, there were relatively low numbers of nests found at Kesterson in 1998, and nesting success was poor for all species monitored. Poor nesting success for ducks and shorebirds may have been due to physical factors such as the loss of habitat as the ephemeral pools dried (this has been observed in other years), which exposed nests to predators. As in other years, there was a high percentage of nest predation among ground-nesting species. The conditions for nesting have changed due to a number of factors such as variations in climatic conditions (e.g., rainfall and temperature), conversion of Kesterson from a wetland to a terrestrial ecosystem, successional changes in vegetation causing plant species changes and structural changes in habitat, and disturbance during the reproductive season from monitoring and management activities.

Of the killdeer eggs collected at Kesterson, the percent of nests lost to predation (60 percent) was higher than the percent of successful nests (23 percent). This was also higher than the predation rate of 36 percent from 1984 – 1985 at Kesterson (Ohlendorf et al. 1989). Killdeer eggs collected from the interior and west side of Kesterson had a higher geometric mean selenium concentration than those collected along the San Luis Drain on the east side. The geometric mean selenium concentration in killdeer eggs (8.0 ppm) and black-necked stilts (12 ppm) were within the suggested level of concern for clutch viability for stilts (6 – 15 ppm; NIWQP 1998), many of the eggs were above the concentrations expected to produce embryo toxicity and teratogenesis. Although hatching success was low due to predation and abandonment, selenium-related effects on bird reproduction at Kesterson were not found, and they have not been found since the filling operation. Many eggs continue to have selenium levels above median background levels of 3 ppm or less, and 74 of the 98 eggs (76 percent) collected from nests at Kesterson had selenium concentrations above the 4.5 to 5.0 ppm threshold level for above-background contamination for the region (Joseph Skorupa, USFWS, personal communication). Twenty-eight eggs (29 percent) were above the suggested avian threshold for reproductive impairment of 10 ppm (Heinz, 1996). Thus, the potential for selenium-induced reproductive problems continues to exist at Kesterson. The results of the studies being conducted at UC Davis (incubating duplicate eggs collected from nests) may provide some additional information on the potential for reproductive problems for birds at Kesterson.

Wild Bird Blood-Se

Wild terrestrial birds, primarily hawks, falcons, owls, and shrikes (some white-crowned sparrows and a western kingbird were also sampled) were trapped, banded (with a federal band), and sampled (blood) from 1994 – 1998 to monitor selenium concentrations in terrestrial birds using Kesterson throughout the year. In addition to adults and immature birds, nestlings of kestrels, northern harriers, and barn owls also were sampled.

Kesterson was the focus of the sampling effort but other areas were sampled also as reference areas. Lands surrounding Kesterson for an approximate 16-km radius (generally bounded by the cities of Stevinson, Gustine, Los Banos, and Santa Nella) represented another study area (referred to as Kesterson Area) that contained primarily agricultural lands (row crops, orchards, and pasture) and seasonal wetland habitats. Other study areas were located approximately 200km north of Kesterson in the Sacramento Valley of California in the counties of Yolo, Solano, and San Joaquin; and approximately 130km northwest of Kesterson near Suisun Marsh (Bay-Delta). Except for the Bay-Delta study area, which was mostly wetland, habitats in these areas were mostly agricultural, similar to those of the Kesterson Area. Limited trapping for American kestrels was also conducted during November, 1995, in agricultural areas adjacent to the Salton Sea, located in the Imperial Valley of California, approximately 1,100km south of Kesterson.

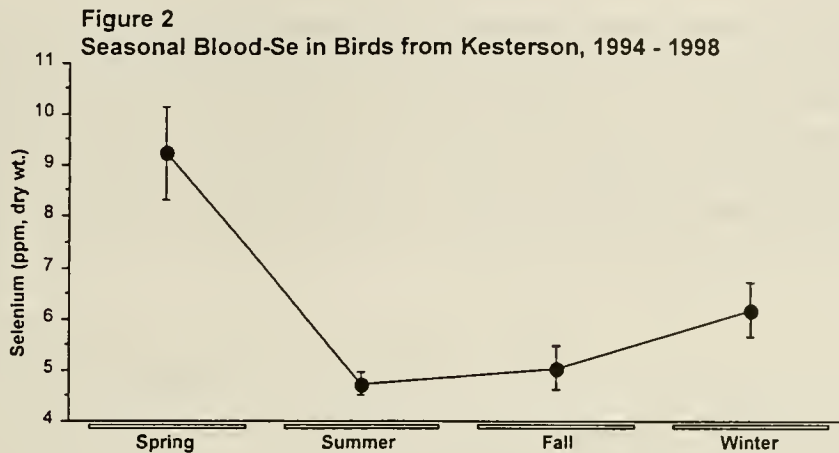
One hundred twenty four individual adult birds were sampled (including eight meadowlarks and five killdeer collected for tissue sampling) and 111 were banded at Kesterson in 1998 (Table 6). Selenium concentrations in blood (blood-Se) were highest in the passerines (loggerhead shrikes, western kingbird, and white-crowned sparrows) and lowest in barn owls. Blood-Se is an indication of dietary exposure, and after about 35 days there is about a 1:1 ratio between diet and blood-Se (Yamamoto et al. 1998). Therefore, these blood levels probably reflect the minimum dietary exposure for these individuals. Birds that were trapped in the spring had slightly higher blood-Se concentrations than those trapped in either the fall or winter (Figure 2). Winter-caught birds had highly variable blood-Se concentrations ranging from 3.3 to 12 ppm. The reason for this may be that the birds trapped in fall and winter had recently arrived and were feeding over large areas, whereas many of those sampled in the spring may have been breeding at Kesterson and foraging over smaller ranges nearer their nests within Kesterson. All the birds trapped at Kesterson in 1998 appeared healthy based on visual examination and body weight (i.e., body weights were within the normal range for the gender and species).

TABLE 6
Blood-Se Concentrations (ppm dry weight) in Wild Birds Trapped^a at Kesterson, 1998

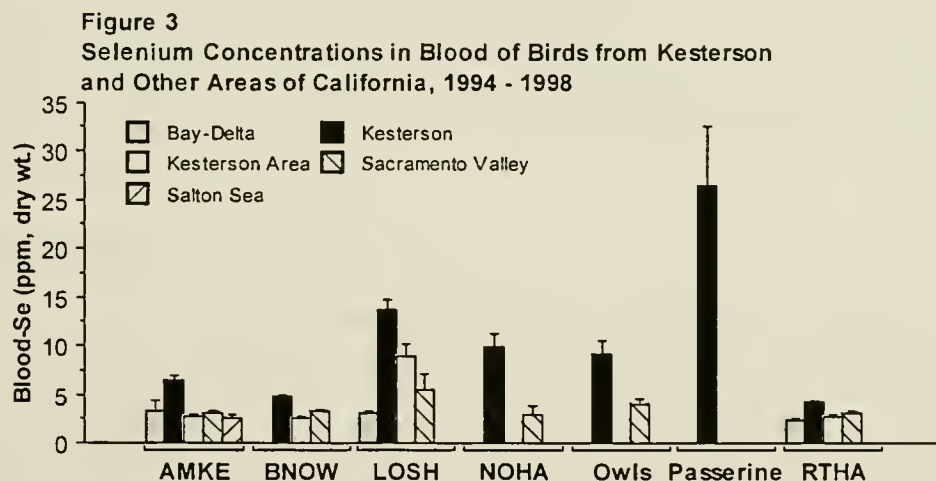
Species	<i>n</i>	Geometric Mean ^b		Range
American kestrel	55	5.4	B	1.5 - 28
Barn owl	33	4.4	B	2.3 - 10
Loggerhead shrike	16	16	A	7.5 - 38
Other passerines	7	22	A	7.4 - 64

^a Does not include birds not banded and released (i.e., western meadowlarks and killdeer).

^b Means sharing the same letter are not significantly different ($P = 0.05$).



Within species, comparisons showed that blood-Se was significantly higher in kestrels and in shrikes from Kesterson than those from the Kesterson area. Kestrels from the Kesterson area had similar blood-Se levels to those from other areas trapped. Loggerhead shrikes from both Kesterson and the Kesterson Area had higher blood-Se than shrikes from the Sacramento Valley and Bay-Delta study sites, respectively (Figure 3). When data for all species were combined, mean blood-Se in birds from Kesterson (5.2 ppm) was significantly higher than in birds from the Kesterson Area (2.7 ppm), Sacramento Valley (3.2 ppm), Bay-Delta (2.5 ppm), or Salton Sea (2.5 ppm). Both individual and combined species blood-Se data are in agreement with current monitoring data from Kesterson showing consistently high levels of selenium in prey species and other biota.



Note: American kestrel (AMKE), barn owl (BNOW), loggerhead shrike (LOSH), northern harrier (NOHA), western screech owls, burrowing owls, and great owls (OWLS), white-crowned sparrows and western kingbird (Passerine), red-tailed hawk (RTHA)

Among species at Kesterson, loggerhead shrikes, white-crowned sparrows, and northern harriers had significantly higher blood-Se than American kestrels, barn owls, and red-tailed hawks. A number of factors contribute to these species differences in blood-Se. These factors

probably include the relative time each species spent foraging within Kesterson, which is influenced by both season and home range characteristics; dietary exposure (i.e., various dietary items contain differing concentrations of selenium); and species-specific differences in selenium metabolism. Based on previously reported home ranges of these species and on observations at Kesterson, the highest blood-Se levels observed in loggerhead shrikes and northern harriers are probably due in large part to these birds spending more time foraging within Kesterson. Sampling of retrapped birds did not show any trend of selenium accumulation.

Nest Box and Telemetry Studies

Six of 30 nest boxes (20 percent occupancy) located on Kesterson and two off-site nest boxes (40 percent occupancy) were used by American kestrels. All three barn owl nest boxes were used (barn owls had seven nest attempts; one nest box was used three times and two were used twice) during 1998. American kestrel nest success was 67 percent. One kestrel nesting attempt in south Pond 1 failed during incubation. It is assumed that the female died (possibly killed by a predator) and starlings destroyed the eggs. Barn owl nest success was 50 percent. Barn owl nests failed twice due to predation and twice due to apparent abandonment.

An egg was collected from each nest (that was found during incubation) and blood samples were collected from parents and their young. The results of blood-Se were extremely variable in parent American kestrels (kestrel, 2.4 to 27; barn owl, 3.6 to 5.6 ppm Se) and in their chicks (kestrel, 2.7 to 28; barn owl, 3.5 to 8.1 ppm Se). However, egg selenium concentrations were generally low (kestrel, 2.3 - 5.0 ppm; barn owl, 2.4 - 6.7 ppm Se).

Five adult male kestrels nesting at Kesterson were equipped with telemetry to determine foraging patterns during this time period. Initial analysis of telemetry data indicated that male kestrels nesting at Kesterson forage between 32 and 92 percent on-site and average about 53 percent foraging on Kesterson. However, there are specific techniques for determining ranges using telemetry data that must be applied before the amount of on-site foraging can be determined accurately.

Small Mammals

Selenium concentrations in small mammals collected from Kesterson in 1998, as in other years, are above the < 1 - 4 ppm range suggested as background in mammals (NIWQP 1998). No adverse effects known to be associated with selenium toxicity were observed in mammals collected from 1987 - 1998, in agreement with 1984 findings of Clark (1987). Fluctuations in small mammal populations observed over this time can be attributed to climatic changes (i.e., the drought from 1988 to 1994, regional flooding in 1997, and the El Niño weather pattern in 1998), changes in plant species composition and structure due to succession, and other such factors of natural variation. Various measurements (i.e., body weight, length, condition) were not correlated with selenium concentration and were comparable to published "normal" measurements.

A significant finding in small mammals collected in 1998, assuming that the identification was correct, was a high frequency of possible intersex individuals across four species. Three of the 105 small mammals collected in 1995 also showed this abnormality. We have not been

able to find this abnormality described in the literature, nor have we found other biologists who have observed this phenomenon in a wild population. However, in few other areas have small mammals been monitored as intensively as they have been monitored at Kesterson. Identification of these animals as intersexes is, as of yet, based solely on gross necropsy and professional opinion. At this time the identification of these individuals as intersexes seems to be the most plausible explanation based on the small amount of information available.

The cause of this abnormality is unknown. Laboratory studies of primate, hamster, rat, and mouse reproduction using various forms of selenium have not shown this effect. However, exposure to the agent that caused the formation of intersex offspring probably would be to the female parent prior to or during pregnancy. Similar abnormalities have been produced by causing genetic mutations in laboratory mice (Aronson 1998, Vainio et al. 1999, Parr and McMahon 1998). However, mutations in these experiments were not restricted to the reproductive system as they appear to be in animals captured at Kesterson. If the intersex abnormality was seen across four species it is unlikely that it is the result of a genetic mutation and it is probably the result of environmental influences. It seems more likely that some environmental agent is disrupting early embryonic development and tissue differentiation via exposure of adult females. However, Kesterson is a fairly 'closed system'; it no longer receives drainwater, there is no insecticide or herbicide application within the site, and there are no other obvious contaminant sources within the area. Thus, naturally occurring agents should also be considered as having a role in this phenomenon. It is also unknown whether this is a more widespread phenomenon that was only found at Kesterson because of the intensive biological monitoring conducted there. This phenomenon may be more widespread. As a result of the observations made at Kesterson, other rodents trapped in 1998 were also examined for the occurrence of intersexes. Preliminary results of trapping along the coast in Orange County during November 1998 found as many as 6 percent of 95 rodents collected were identified as intersexes (G. Santolo, unpublished data). These animals were not in reproductive condition and more study needs to be done to confirm this finding.

Although no selenium effects have been found in small mammals, data collected on these species provide information on selenium in the food chain and the exposure to predatory species of concern. The apparent high frequency of intersex mammals found at Kesterson in 1998 suggests the presence of an environmental stressor(s) and warrants further study. Studies to answer questions on the frequency and cause of this phenomenon are underway.

Bird Populations

In general, birds associated with terrestrial habitats showed little change in daily use while those associated with wetland habitats increased in 1998 over previous years. Since 1995, daily use surveys for terrestrial species (represented by raptors and swallows) have not shown significant changes. The surveys suggest that the number of terrestrial birds using Kesterson from 1996 – 1998 is slightly (though not significantly) lower than in the years before 1996. Raptor use (including red-tailed hawks, northern harriers, white-tailed kites, and American kestrels) generally follows a pattern of a large decrease in numbers followed by an increase over about a three-year period at Kesterson. This was seen from 1989 to 1991, again in 1992 to 1994, and to a lesser degree from 1996 to 1998. This population trend seems to follow the small mammal population density (based on trap success data; CH2M HILL

1997). In 1998, persistent ephemeral pools late into the breeding season reduced the foraging area for terrestrial predators and possibly the prey base as well. Because the raptor population is below the number supported in 1991 and 1994, there is potential for the number of these birds to continue to increase if other factors (terrestrial foraging habitat and prey base) are favorable in the future.

The number of swallows (tree, barn, and cliff swallows) counted at Kesterson has varied over the years they have been monitored, but has not changed significantly since 1989. These birds are aerial insectivores and typically forage over grasslands and wetlands. Therefore, the changes from grassland habitat to wetland (analogous to dry- and wet-years) appear to have little effect on the population of swallows observed at Kesterson.

Blackbirds (red-winged, tricolored, and yellow-headed blackbirds) are terrestrial birds associated with wetland habitats. Use of Kesterson by blackbirds increased in 1998 and use was significantly higher than the number of blackbirds observed in 1989 to 1991 and in 1994. More habitat and food resources were available for these birds. However, based on nest observations, few blackbirds nested successfully at Kesterson.

Killdeer and other shorebirds (black-necked stilts, American avocets, greater yellowlegs, long-billed curlews, and sandpipers) increased significantly since 1997. Killdeer have been increasing since 1994 and their daily use of Kesterson nearly doubled from 1997 to 1998. Killdeer and other shorebirds were apparently attracted by the persistent ephemeral pools in 1998 that provided feeding and nesting opportunities.

Nocturnal Surveys

During nocturnal surveys conducted in the fall of 1998, avian predators that were observed were barn owls, great horned owls, and short-eared owls. Skunks, hares and rabbits, and coyotes were the mammals observed (Table 7). No San Joaquin kit fox were observed during these surveys. Comparing the frequencies of species occurrence in fall of 1998 with the spring and summer frequencies observed in 1995, the spring and fall barn owl frequency reflects a similar seasonally resident population at Kesterson. Not much is known about the seasonal movements of barn owls, but it is thought that the adults are fairly sedentary and do not migrate (Marti, 1992). Summer is when barn owl young are dispersing in the greatest numbers (although they breed throughout the year at Kesterson) and the high percent-frequency in the summer of 1995 is probably due to young dispersing from their natal areas. In contrast, mammal frequencies were highest in the spring at the time their young would be expected to be dispersing. This information suggests that the resident population for these species has remained fairly stable since 1995.

TABLE 7
Frequency of Sightings (percent of total sightings) During Nocturnal Surveys

	Barn Owl	Great Horned Owl	Short-eared Owl	Rabbit	Hare	Skunk	Coyote
1998 Fall	19	2	12	29	29	2	7
1995 Spring	11			4	44		15
1995 Summer	68			3	12		5

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2. Habitat Description and Vegetation Surveys

Objectives

The purpose of the 1998 vegetation study at the site was to assess potential changes in the plant species in terms of presence and cover. These data allow tracking of changes in wildlife habitat that can then be compared with wildlife use. Further, data collection from vegetation and physical environmental parameters can be analyzed to assess (1) vegetation type changes in composition and structure; (2) how the different plant species and vegetation types, in the different habitat areas at the site, are accumulating and processing selenium; (3) what vegetational change may occur in the future; and (4) what vegetation and habitat management could be implemented to improve wildlife habitat and reduce selenium toxicity concerns regarding wildlife species.

The terrestrial wildlife habitat at Kesterson is currently a mixture of alkali desert scrub and native and non-native annual grassland plant communities. Salt-tolerant (halophytic) vegetation of alkali desert scrub communities includes perennial saltbush (*Atriplex polycarpa*), iodinebush (*Allenrolfea occidentalis*), alkali blite (*Bassia hyssopifolia*), alkali heath (*Frankenia salina*), alkali weed (*Cressa truxillensis*), and saltgrass (*Distichlis spicata*) (Rowlands 1988).

Dewatering and filling of low areas at Kesterson Reservoir was conducted in 1988 (Ohlendorf and Santolo 1994). These dewatered and filled areas form a mosaic of vegetation, and have been classified into three types for the purposes of vegetation monitoring. These include: filled areas that were created after the drainage of the wetlands; open areas that were dominated by cattail (*Typha* sp.) prior to wetland drainage and which were later disced; and grassland areas dominated by saltgrass that represented upland areas not altered during the draining and filling process. These three vegetation types are referred to in this report as Filled, Open, and Grassland.

In addition to the native alkali desert scrub habitat and this mosaic of three created habitats, localized remnant areas of perennial grasslands, including alkali sacaton (*Sporobolus airoides*) grasslands and creeping wildrye (*Leymus triticoides*) grasslands, are also found at Kesterson.

Methods

Previous Studies

Previous studies at Kesterson during 1989 to 1995 have included vegetation monitoring and habitat characterization. Vegetation monitoring included collecting data on the frequency and percent cover of plant species within Filled, Open, and Grassland habitats. Habitat characterization included evaluating the environmental parameters (e.g., soil morphology, composition, and soil moisture) of the three created habitat types as well as other areas (e.g., native grasslands).

Kesterson was divided geographically into three areas (Trisections) and permanent transects were established within these vegetation types. Because the three different vegetation types occurred throughout Kesterson, each type was originally represented in all three Trisections. Permanent 1.5-m² plots were placed randomly along existing transects, and transect intervals were established for wildlife monitoring. The plots were marked in the field using six-foot wooden stakes.

Plant species encountered within the transect intervals were identified, their occurrences tallied, and their relative frequency (percent) calculated. These data were collected during January through March of 1989, January through May of 1990, and April through September of 1991, 1992, and 1993. In addition, the percent vegetation cover by species and phenological stage of development were recorded. During 1994 and 1995, only percent cover was taken; other data such as plant phenology and plant numbers were not obtained. In 1998, plant species and percent cover were collected where the permanent plot markers could still be located.

Vegetation data from 1991 – 1993 were analyzed using two-way indicator species analysis (TWINSPAN, Hill 1979); vegetation data from 1993 – 1994 were analyzed using partial detrended canonical correlation analysis (CANOCO, Ter Braak, 1988). TWINSPAN is best suited for classifying vegetation data and in determining the constancy of vegetation types, while CANOCO is a better statistical tool with which to examine the species and sample relationships, either in terms of similarities or differences, that vary along different environmental gradients. Results of the CANOCO analysis also provided additional information on whether the three plant associations are distinct habitats or whether they represent a range of plant species associations.

Results of the above multivariate statistical analyses suggested that the three vegetation types (Filled, Open, and Grassland) are not consistent habitat types since no substantive differences or similarities between habitat types were observed. Results of TWINSPAN and CANOCO analyses also showed a lack of clear relationships between species and habitats, and considerable variation was found within each habitat type. It was suggested that the vegetation structure and plant species composition likely is a reflection of the high levels of disturbance present and the prevalence of non-native weedy plant species found in all habitat types.

Soils Analyses

In 1994, analysis of soil samples within the three habitat types (Filled, Open, and Grassland) identified some ecologically meaningful soil parameters that showed statistically significant differences between sites. These parameters include nitrogen (ammonia), phosphorus, pH, and percent clay. However, other statistical differences such as organic matter, albeit present, were so small that they were deemed ecologically insignificant. Larger differences were observed between created habitats (Filled, Open, and Grassland) and the native sacaton grassland and creeping wildrye grassland habitats.

Soil moisture data were also obtained from created habitat types in 1994. These data indicated that soils in the Filled habitat type dried earliest in the season, followed by soils in Grassland and then Open habitat.

Studies During 1998

Field investigations during 1998 were conducted to collect percent cover data along five previously established belt transects (1A, 1B, 2A, 2B, and 3) in the Open, Filled, and Grassland areas. A total of 53 1.5-m² plots were sampled along the Trisection intervals within these plant associations. The total number of plots sampled in 1998 has decreased significantly from those originally included in vegetation monitoring (96 plots were originally established).

The decrease in sample plots was caused by the loss of plots due to trampling by cattle (predominantly in Trisection 3 and in some areas in Trisection 2) and breakage of plot stakes due to unknown variables. The ruderal plant species that form the dominant vegetation cover have now reached a height of several feet, obscuring both the 3-foot tall plot stakes and the 5-foot tall transect stakes. Once broken, the stakes are extremely difficult to relocate and identify the location of the vegetation plot. The remaining stake end could in some instances be located and the plot number could be determined with confidence. However, in many instances the plot stake was either missing or the exact plot location could not be determined in the field and these plots were not included in monitoring.

A summary of the number of sample plots that could still be located during the 1998 field season is provided in Table 1.

TABLE 1
Summary of 1998 Vegetation Sampling Program

Habitat Type	May 1998	July 1998	August 1998
Trisection 1, Grassland	2 of 2 plots	2 of 2 plots	2 of 2 plots
Trisection 1, Filled	11 of 12 plots	11 of 12 plots	11 of 12 plots
Trisection 1, Open	5 of 7 plots	6 of 7 plots	6 of 7 plots
Trisection 2, Grassland	11 of 13 plots	11 of 13 plots	11 of 13 plots
Trisection 2, Filled	12 of 17 plots	15 of 17 plots	15 of 17 plots
Trisection 2, Open	5 of 7 plots	7 of 7 plots	7 of 7 plots
Trisection 3, Grassland	4 of 9 plots	3 of 9 plots	3 of 9 plots
Trisection 3, Filled	6 of 16 plots	4 of 16 plots	2 of 16 plots

Vegetation sampling was conducted in May 1998, to include spring-season plants; in July 1998 for early-summer flowering plants; and in August 1998, for late-summer flowering plants. Plant species observed within 1.5-m² plots were identified, and each of the following categories was recorded in each sample plot: percent cover by species, percent cover of bare ground, dead plant material, saltgrass, and cattail thatch. The average percent cover value by species for all sampling sessions was obtained and is discussed in the Results section below.

Results and Discussion

Sample plots in Filled habitat contain saltgrass, alkali weed, five-hooked bassia, and dock (*Rumex dentatus*). Filled plots also contain non-native annual grasses along the three Trisections. Dominant or co-dominant annual or biennial non-native plant species include annual beard grass (*Polypogon monspeliensis*), Italian ryegrass (*Lolium multiflorum*), soft chess (*Bromus hordeaceus*), ripgut grass (*Bromus diandrus*), Mediterranean barley (*Hordeum murinum* ssp. *gussoneanum*) and farmer's foxtail (*Hordeum murinum* ssp. *leporinum*).

Sample plots in the Grassland habitat type were dominated by saltgrass, a perennial native grass, with annual grasses (e.g., ripgut brome) making up the subdominant component. Grassland plots also contained alkali weed, a native perennial halophytic (salt-loving) species.

Plant species that were dominant in Open water plots included two perennial native species, alkali weed and saltgrass. Non-native annual species prevalent in the Open water habitat also included: annual beard grass, five-hooked bassia, and Mediterranean barley.

Bare ground cover values were higher than 10 percent in all habitat types in all Trisections except for Grassland habitat in Trisections 2 and 3. Standing water was observed in Trisections 1 and 2 (with the exception of Grassland habitat in Trisection 2). Standing water was not observed in sample plots in either Filled or Grassland habitats in Trisection 3. The presence of standing water is due to the abnormally high amount of precipitation that occurred at Kesterson in later-winter and early-spring.

1998 Growing Season Conditions

Within the Filled and Open plots in Trisections 1 and 2 the average percent cover value for the bare ground category was the largest percent cover value (Tables 2, 3, and 4). This is attributed in part to the delayed growth of many plants due to above average precipitation combined with seasonally cool temperatures. Above average precipitation fell in late-winter and early spring (with 7.7 inches falling in February and 2.05 inches in March). Spring and summer temperatures were cooler than normal, reaching a maximum of 97 degrees Fahrenheit in August. A significant amount of standing water was present at Kesterson (predominantly in the Open water habitat and in areas of low topography in Filled habitat types) until late spring. Soils in the Grassland habitat type were extremely saturated until late spring but ponding water was not observed in Grassland sample plots. Many early-blooming plants such as annual grasses and forbs did not flower or set seed until summer, and late-blooming species (such as species in the genus *Atriplex*) did not flower until after the last sampling period was conducted in July. Less dead plant cover and thatch was detected in all habitats and Trisections in 1998 than in previous years with normal rainfall and temperature.

Average Percent Live Cover—Trisection 1 (refer to Table 2)

Filled Habitat

Two non-native annual grasses (Italian ryegrass and Mediterranean barley) formed the dominant grass cover in Filled plots in Trisection 1 (cover values of 6.2 and 6.3 percent).

TABLE 2

Plants Observed at Kesterson Reservoir in 1998

Scientific Name	Common Name	AVERAGE PERCENT COVER MAY-AUG GRASSL - T1	AVERAGE PERCENT COVER MAY-AUG FILLED - T1	AVERAGE PERCENT COVER MAY-AUG OPEN - T1
<i>Atriplex argentea</i> var. <i>mohavensis</i> .	Saltbush	0.00	0.00	0.00
<i>Atriplex canosa</i>	Saltbush	0.00	0.00	0.00
<i>Atriplex coronata</i> var. <i>coronata</i>	Saltbush	0.00	0.00	0.00
<i>Atriplex lentiformis</i>	Saltbush	0.00	0.00	0.00
<i>Atriplex polycarpa</i>	Perennial saltbush	0.00	0.00	0.00
<i>Atriplex rosea</i>	Saltbush	0.00	0.00	0.00
<i>Atriplex semibaccata</i>	Australian saltbush	0.00	0.00	0.00
<i>Atriplex serenana</i> var. <i>serenana</i>	Saltbush	0.00	0.00	0.00
<i>Atriplex</i> sp.	Saltbush	0.00	2.39	0.28
<i>Avena barbata</i>	Slender wild rye	0.00	0.00	0.00
<i>Bassia</i> (dead)	Five-hooked bassia (dead)	0.00	5.09	6.68
<i>Bassia hyssopifolia</i>	Five-hooked bassia	5.83	6.39	7.44
<i>Brassica kaber</i>	Charlock	0.00	0.00	0.00
<i>Bromus diandrus</i>	Ripgut brome	17.00	5.64	4.02
<i>Bromus mollis</i>	Soft chess	0.00	0.18	0.11
<i>Bromus rubens</i>	Red brome	0.00	0.00	0.11
<i>Capsella bursa-pastoris</i>	Shepherd's purse	0.00	0.00	3.33
<i>Centaurea</i> sp.	Star thistle	0.00	0.00	0.11
<i>Cotula coronopifolia</i>	Brass buttons	0.00	0.03	0.00
<i>Cressa truxillensis</i>	Alkali weed	1.00	2.52	10.07
<i>Crypsis</i> sp.	Prickle grass	0.00	0.64	0.33
<i>Distichlis</i> (thatch)	Saltgrass thatch	2.50	0.45	0.00
<i>Distichlis spicata</i>	Saltgrass	41.50	0.06	0.00
<i>Erodium botrys</i>	Log-beaked filaree	0.00	0.00	0.00
<i>Erodium cicutarium</i>	Red-stemmed filaree	0.00	0.00	0.00
<i>Erodium moschatum</i>	White-stemmed filaree	0.00	0.00	0.00
<i>Festuca myuros</i>	Annual fescue	0.00	0.00	0.00
<i>Frankenia grandifolia</i> var. <i>campestris</i>	Alkali heath	0.50	2.48	0.30
<i>Haplopappus acradenius</i> spp. <i>bracteosus</i>	Goldenbush	0.00	0.00	0.00
<i>Hemizonia</i> sp.	Spikeweed	0.00	0.00	0.00
<i>Hordeum depressum</i>	Low barley	0.00	0.00	0.00
<i>Hordeum murinum</i> spp. <i>gussoneanum</i>	Mediterranean barley	0.00	6.33	5.93
<i>Hordeum murinum</i> spp. <i>leporinum</i>	Farmer's foxtail	0.00	0.45	0.11
<i>Lactuca serriola</i>	Prickly lettuce	3.33	0.88	1.04
<i>Lolium multiflorum</i>	Italian ryegrass	0.17	6.21	2.28
<i>Lolium perenne</i>	Perennial ryegrass	0.00	0.12	0.00
<i>Matricaria occidentalis</i>	Pineapple weed	0.00	0.00	0.00
<i>Medicago polymorpha</i>	Bur clover	0.00	0.00	0.00
<i>Melilotus</i> sp.	Sweetclover	0.50	0.45	1.70
<i>Polygonum patulum</i>	Smartweed	0.00	0.00	0.00
<i>Polypogon monspeliensis</i>	Rabbit's foot grass	0.00	5.30	10.72
<i>Rumex dentatus</i> spp. <i>klotzschianus</i>	Dock	0.00	6.39	3.29
<i>Salicornia subterminalis</i>	Pickleweed	0.00	0.00	0.00
<i>Salsola pestifera</i>	Russian thistle	0.00	0.00	0.00
<i>Scirpus californicus</i>	California tule	0.00	0.00	0.34
<i>Senecio vulgaris</i>	Common groundsel	0.00	0.00	0.00
<i>Sesuvium verrucosum</i>	Sea-purslane	0.00	0.03	0.39
<i>Sida leprosa</i> var. <i>hederaceae</i>	Alkali mallow	0.00	0.00	0.00
<i>Sisymbrium</i> sp.	Mustard	0.00	0.00	0.00
<i>Sonchus</i> sp.	Sowthistle	0.00	0.03	0.00
<i>Spergularia marina</i>	Sand spurry	0.00	0.00	0.00
<i>Suaeda fruticosa</i>	Alkali blite	0.00	0.00	0.00
<i>Typha</i> sp.	Cattail	0.00	0.27	0.37
Unk. herb		0.00	0.03	0.00
Thatch		4.17	7.61	9.78
Open water		0.00	4.97	5.73
Bare ground		23.50	35.03	25.52
Percentage of total plant cover (includes thatch and dead vegetation).		76.50	60.00	68.74
Percentage of total plant cover of dominant species in Tnsection 1.		74.33	51.48	61.27
Percentage of total plant cover from dominant species		97.16	85.80	89.13
Live percent cover		69.83	46.85	52.29

Dock and five-hooked bassia were co-dominant with the grassland species (6.4 and 6.4 percent). All four of these dominant species are more tolerant of wetter conditions than other non-native grasses and forbs at Kesterson, and their prevalence in the Filled habitat type is attributed to the above average rainfall at Kesterson. Bare ground (35.0 percent) and thatch (7.6 percent) had higher percent cover values than any of the live plant species. The amount of bare ground, open water, dead vegetation, and thatch is included in this average percent cover calculation.

Open Habitat

Similar to the Filled habitat type in Trisection 1, bare ground had the highest cover value (23.1 percent). The dominant vegetation within the Open habitats in Trisection 1 included annual beard grass with a cover value of (15.6 percent), alkali weed (with a cover value of 10.5 percent), bassia (live) with a cover value of 9.0 percent and bassia (dead) with a cover value of 8.4 percent. Standing water was present in the plot until late in the season as evidenced by the cover value of 7.2 percent for open water.

Grassland Habitat

Grassland habitat within Trisection 1 is dominated by saltgrass, a native perennial grass with an average cover value of 41.5 percent. The next most important plant species in terms of average percent live cover value is ripgut brome (with a cover value of 17.0 percent). No other non-native annual grasses are considered dominant in this habitat type. Two ruderal species, five-hooked bassia and prickly lettuce (*Lactuca serriola*), have cover values of 5.8 percent and 3.3 percent, respectively. Bare ground had a percent cover value of (23.5 percent).

Average Percent Live Cover—Trisection 2 (refer to Table 3)

Filled Habitat

Bassia (dead) had the largest vegetation cover value (10.2 percent). Two native perennial species, *Atriplex* sp., and alkali weed had the highest percent cover values (7.9 and 7.8 percent). Five-hooked bassia, saltgrass, and annual beard grass had similar cover values of 7.2, 7.0, and 6.8 percent. These dominant species are tolerant of wetland conditions, and their prevalence in the Filled habitat is attributed to the above average precipitation levels at Kesterson. Bare ground had the largest percent cover value within Filled habitat in Trisection 2 (30.4 percent). Standing water had a cover value of 7.2 percent.

Open Habitat

The Open habitat within Trisection 2 was dominated by two native perennial species: alkali weed and saltgrass (with cover values of 12.3 and 11.7). The next largest average live cover values were observed in annual beard grass, a wetland tolerant non-native annual grass species, with a cover value of 7.5 percent. Dead bassia had a cover value of 6.7. Open water was present during the first sampling session and it had a cover value of 9.4 percent. A high cover value for bare ground was observed in the Open water habitat in Trisection 2 (a cover value of 36.1 percent).

TABLE 3
Plants Observed at Kesterson Reservoir In 1998

Scientific Name	Common Name	AVERAGE PERCENT COVER MAY-AUG GRASSL - T2	AVERAGE PERCENT COVER MAY-AUG FILLED - T2	AVERAGE PERCENT COVER MAY-AUG OPEN - T2
<i>Agrostis avenaceae</i>	Hairy-flowered bent grass	0.00	0.00	0.24
<i>Atriplex argentea</i> var. <i>mohevensis</i> .	Saltbush	0.00	0.00	0.00
<i>Atriplex canosa</i>	Saltbush	0.00	0.00	0.00
<i>Atriplex coronata</i> var. <i>coronata</i>	Saltbush	0.00	0.00	0.00
<i>Atriplex lentiformis</i>	Saltbush	0.00	0.00	0.00
<i>Atriplex polycarpa</i>	Perennial saltbush	0.00	0.00	0.00
<i>Atriplex rosea</i>	Saltbush	0.00	0.00	0.00
<i>Atriplex semibaccata</i>	Australian saltbush	0.00	0.00	0.00
<i>Atriplex serotena</i> var. <i>serotena</i>	Saltbush	0.00	0.00	0.00
<i>Atriplex</i> sp.	Saltbush	0.15	7.57	3.05
<i>Avena barbata</i>	Slender wild rye	0.03	0.00	0.00
<i>Bassia</i> (dead)	Five-hooked bassia (dead)	0.00	10.62	6.06
<i>Bassia hyssopifolia</i>	Five-hooked bassia	0.06	5.82	0.90
<i>Brassica kaber</i>	Charlock	0.00	0.00	0.00
<i>Bromus diandrus</i>	Ripgut brome	13.79	0.04	3.38
<i>Bromus mollis</i>	Soft chess	2.12	0.05	0.00
<i>Bromus rubens</i>	Red brome	0.00	0.00	0.00
<i>Capsella bursa-pastoris</i>	Shepherd's purse	0.00	0.00	0.00
<i>Centaurea</i> sp.	Star thistle	0.09	0.00	0.00
<i>Colula cronopifolia</i>	Brass buttons	0.00	0.00	0.00
<i>Cressa truxillensis</i>	Alkali weed	3.82	10.36	10.24
<i>Crypsis</i> sp.	Prickle grass	0.00	0.04	0.00
<i>Distichlis</i> (thatch)	Saltgrass thatch	0.15	0.00	0.00
<i>Distichlis spicata</i>	Saltgrass	41.55	6.08	9.28
<i>Erodium botrys</i>	Log-beaked filaree	0.00	0.00	0.00
<i>Erodium cicutarium</i>	Red-stemmed filaree	0.00	0.00	0.00
<i>Erodium moschatum</i>	White-stemmed filaree	0.00	0.00	0.00
<i>Festuca myuros</i>	Annual fescue	0.00	0.00	0.00
<i>Frankenia grandifolia</i> var. <i>campestris</i>	Alkali heath	1.61	3.39	0.00
<i>Heplopappus acradenioides</i> spp. <i>bracteoides</i>	Goldenbush	0.00	0.00	0.00
<i>Helianthus annuus</i>	Common sunflower	0.03	0.00	0.00
<i>Hemizonia</i> sp.	Spikeweed	0.00	0.00	0.00
<i>Hordeum depressum</i>	Low barley	0.00	0.00	0.00
<i>Hordeum murinum</i> spp. <i>gussoneanum</i>	Mediterranean barley	3.21	1.85	0.00
<i>Hordeum murinum</i> spp. <i>leporinum</i>	Farmer's foxtail	7.52	0.08	0.13
<i>Juncus</i> sp.	Rush	0.24	0.00	0.00
<i>Lactuca scariola</i>	Prickly lettuce	4.76	0.52	2.57
<i>Lolium multiflorum</i>	Italian ryegrass	0.00	0.00	0.00
<i>Lolium perenne</i>	Perennial ryegrass	0.00	0.00	0.00
<i>Malvella leprosa</i>	Alkali-mallow	0.00	0.00	0.95
<i>Matricaria occidentalis</i>	Pineapple weed	0.00	0.00	0.00
<i>Medicago polymorpha</i>	Bur clover	0.00	0.00	0.00
<i>Melilotus</i> sp.	Sweetclover	0.48	0.41	0.07
<i>Polygonum patulum</i>	Smartweed	0.00	0.00	0.00
<i>Polypogon monspeliensis</i>	Rabbit's foot grass	0.15	6.54	10.10
<i>Rumex dentatus</i> spp. <i>klotzschianus</i>	Dock	3.85	4.08	2.96
<i>Salicornia subterminalis</i>	Pickleweed	0.00	0.00	0.00
<i>Salsola pestifera</i>	Russian thistle	0.00	0.00	0.00
<i>Scirpus californicus</i>	California tule	0.00	0.00	0.10
<i>Senecio vulgaris</i>	Common groundsel	0.00	0.00	0.00
<i>Sesuvium verrucosum</i>	Sea-purslane	0.00	0.22	0.00
<i>Sida leprosa</i> var. <i>hederaceae</i>	Alkali mallow	0.00	0.00	1.19
<i>Sisymbrium</i> sp.	Mustard	0.00	0.00	0.00
<i>Sonchus</i> sp.	Sowthistle	0.00	0.00	0.10
<i>Spergularia mena</i>	Sand spurry	0.00	0.00	0.00
<i>Suaeda frutescens</i>	Alkali blite	0.00	0.00	0.00
<i>Typha</i> sp.	Cattail	0.00	0.09	0.50
<i>Xanthium strumarium</i>	Cocklebur	0.03	0.04	0.00
Unk. herb		0.00	0.00	0.05
Thatch		14.64	2.94	0.71
Bare ground		0.00	32.07	26.57
Open water		14.64	7.19	0.00
Percentage of total plant cover (includes thatch and dead vegetation).		98.27	60.73	52.56
Percentage of total plant cover of dominant species in Trisection 2.		93.12	57.39	47.63
Percentage of total plant cover from dominant species		94.76	94.50	90.62
Live percent cover		83.48	47.18	45.79

Grassland Habitat

Grassland habitat within this Trisection was largely dominated by saltgrass, a native perennial grass (with a cover value of 41.5 percent). The next two highest cover values were observed in two non-native annual grasses, ripgut brome and farmer's foxtail with cover values of 13.8 and 7.5 percent. The thatch category had a cover value of 14.6 percent.

Average Percent Live Cover–Trisection 3 (refer to Table 4)

Filled Habitat

Only Filled and Grassland habitats are represented within Trisection 3. Within the Filled habitat, alkali weed was the dominant live plant species, with an average percent live cover value of 30.7 percent. Other plant species with large average percent cover values within this plot are saltgrass and Mediterranean barley, with cover values of 17.0 and 9.2 percent. Bare ground had a cover value of 9.5 percent. The thatch category had a cover value of 16.3 percent.

Grassland Habitat

The Grassland habitat in Trisection 3 was dominated by two native perennial species: alkali weed, and saltgrass. The cover values for these species are alkali weed (27.7 percent), saltgrass (10.0 percent), and saltgrass thatch (13.8 percent). A non-native annual grass species, ripgut brome, was also very prevalent in the Grassland habitat in Trisection 3 (with a cover value of 13.8 percent). The thatch category was also important in terms of cover (with a value of 23.2 percent).

Total Percent Live Cover by Sampling Season

The total average live percent cover for Kesterson (including all habitat types and Trisections) was calculated. The largest total average live percent cover was observed in Trisection 2 Grassland with a value of 83.5 percent. Grassland also had the highest live cover percentage in Trisection 1, with Filled and Open areas both being lower. The Filled areas of Trisection 3; however, showed a higher percentage of live cover (77.1 percent) than the Grassland areas (69 percent).

Table 5 provides a summary of the dominant cover types by habitat and Trisection.

Number of Plant Species Observed Within Sampling Plots

In all three Trisections, non-native annuals are the dominant vegetation observed within the sample plots, as is typical of disturbed grassland. Appendix A-1 of this report lists all plant species found at Kesterson. The number of non-natives was higher than the number of native species as indicated by Tables 2, 3, and 4. Fewer native perennial species were detected in the 1998 sampling rounds, likely a reflection of the degree of disturbance at Kesterson.

TABLE 4
Plants Observed at Kesterson Reservoir In 1998

Scientific Name	Common Name	AVERAGE PERCENT COVER MAY-AUG	AVERAGE PERCENT COVER MAY-AUG
		GRASSL - T3	FILLED - T3
<i>Atriplex argentea</i> var. <i>mohavensis</i> .	Saltbush	0.00	0.00
<i>Atriplex canosa</i>	Saltbush	0.00	0.00
<i>Atriplex coronata</i> var. <i>coronata</i>	Saltbush	0.00	0.00
<i>Atriplex lentiformis</i>	Saltbush	0.00	0.00
<i>Atriplex polycarpa</i>	Perennial saltbush	0.00	0.00
<i>Atriplex rosea</i>	Saltbush	0.00	0.00
<i>Atriplex semibaccata</i>	Australian saltbush	0.00	0.00
<i>Atriplex serenana</i> var. <i>serenana</i>	Saltbush	0.00	0.00
<i>Atriplex</i> sp.	Saltbush	0.11	3.00
<i>Avena barbata</i>	Slender wild rye	0.00	0.00
<i>Bassia</i> (dead)	Five-hooked bassia (dead)	0.00	1.00
<i>Bassia hyssopifolia</i>	Five-hooked bassia	0.00	0.00
<i>Brassica kaber</i>	Charlock	0.00	0.83
<i>Bromus diandrus</i>	Ripgut brome	19.58	6.97
<i>Bromus mollis</i>	Soft chess	0.00	0.00
<i>Bromus rubens</i>	Red brome	0.00	0.17
<i>Capsella bursa-pastoris</i>	Shepherd's purse	0.00	0.00
<i>Centaurea</i> sp.	Star thistle	0.00	0.00
<i>Cotula coronopifolia</i>	Brass buttons	0.00	0.00
<i>Cressa truxillensis</i>	Alkali weed	18.89	29.83
<i>Crypsis</i> sp.	Prickle grass	0.00	0.00
<i>Distichlis</i> (thatch)	Saltgrass thatch	9.22	0.00
<i>Distichlis spicata</i>	Saltgrass	19.78	20.28
<i>Epilobium paniculatum</i>	Willow-herb	0.94	0.00
<i>Erodium botrys</i>	Log-beaked filaree	0.00	0.00
<i>Erodium cicutarium</i>	Red-stemmed filaree	0.00	0.50
<i>Erodium moschatum</i>	White-stemmed filaree	0.00	0.00
<i>Festuca myuros</i>	Annual fescue	0.00	0.00
<i>Frankenia grandifolia</i> var. <i>campestris</i>	Alkali heath	4.44	0.00
<i>Haplopappus acradenius</i> spp. <i>bracteatus</i>	Goldenbush	0.00	0.00
<i>Helianthus annuus</i>	Common sunflower	0.00	0.00
<i>Hemizonia</i> sp.	Spikeweed	0.00	0.00
<i>Hordeum depressum</i>	Low barley	0.00	0.00
<i>Hordeum murinum</i> spp. <i>gussoneanum</i>	Mediterranean barley	0.22	5.56
<i>Hordeum murinum</i> spp. <i>leporinum</i>	Farmer's foxtail	0.69	0.00
<i>Juncus</i> sp.	Rush	0.00	0.00
<i>Lactuca scariola</i>	Prickly lettuce	3.75	2.53
<i>Lolium multiflorum</i>	Italian ryegrass	0.00	0.00
<i>Lolium perenne</i>	Perennial ryegrass	0.00	0.00
<i>Matricaria occidentalis</i>	Pineapple weed	0.00	0.00
<i>Medicago polymorpha</i>	Bur clover	0.00	0.22
<i>Melilotus</i> sp.	Sweetclover	0.08	5.08
<i>Polygonum patulum</i>	Smartweed	0.00	0.00
<i>Polypogon monspeliensis</i>	Rabbit's foot grass	0.50	0.00
<i>Rumex dentatus</i> spp. <i>klotzschianus</i>	Dock	0.00	0.69
<i>Salicornia subterminalis</i>	Pickleweed	0.00	0.00
<i>Salsola pestifera</i>	Russian thistle	0.00	0.00
<i>Scirpus californicus</i>	California tule	0.00	0.00
<i>Senecio vulgaris</i>	Common groundsel	0.00	0.00
<i>Sesuvium verrucosum</i>	Sea-purslane	0.00	0.00
<i>Sida leprosa</i> var. <i>hederacea</i>	Alkali mallow	0.00	0.00
<i>Sisymbrium</i> sp.	Mustard	0.00	0.00
<i>Sonchus</i> sp.	Sowthistle	0.00	0.00
<i>Spergularia marina</i>	Sand spurry	0.00	0.00
<i>Suaeda fruticosa</i>	Alkali blite	0.00	0.00
<i>Typha</i> sp.	Cattail	0.00	0.00
Unk. Herb.		0.00	1.39
Unk. cotyledon		0.00	0.06
Thatch		17.00	11.17
Mixed veg (dead)		0.00	1.67
Open water		0.00	0.00
Bare ground		4.78	9.06
Percentage of total plant cover (includes thatch and dead vegetation).		95.22	90.94
Percentage of total plant cover of dominant species in Trisection 3.		92.67	84.42
Percentage of total plant cover from dominant species		97.32	92.83
Percent live cover		69.00	77.11

TABLE 5

List of Dominant Cover Types by Habitat and Trisection of Plants Observed at Kesterson Reservoir in 1998

Scientific Name	AVERAGE PERCENT COVER		AVERAGE PERCENT COVER		AVERAGE PERCENT COVER
	MAY-AUG GRASSL - T1	Scientific Name	MAY-AUG FILLED - T1	Scientific Name	MAY-AUG OPEN - T1
<i>Distichlis spicata</i>	41.50	Thatch	7.61	<i>Polypogon monspeliensis</i>	10.72
<i>Bromus diandrus</i>	17.00	<i>Rumex dentatus</i> spp. <i>klotzschianus</i>	6.39	<i>Cressa truxillensis</i>	10.07
<i>Bassia hyssopifolia</i>	5.83	<i>Bassia hyssopifolia</i>	6.39	Thatch	9.78
Thatch	4.17	<i>Hordeum murinum</i> spp. <i>gussoneanum</i>	6.33	<i>Bassia hyssopifolia</i>	7.44
<i>Lactuca serriola</i>	3.33	<i>Lolium multiflorum</i>	6.21	<i>Bassia</i> (dead)	6.68
<i>Distichlis</i> (thatch)	2.50	<i>Bromus diandrus</i>	5.64	<i>Hordeum murinum</i> spp. <i>gussoneanum</i>	5.93
		<i>Polypogon monspeliensis</i>	5.30	<i>Bromus diandrus</i>	4.02
		<i>Bassia</i> (dead)	5.09	<i>Capsella bursa-pastoris</i>	3.33
		<i>Cressa truxillensis</i>	2.52	<i>Rumex dentatus</i> spp. <i>klotzschianus</i>	3.29

Scientific Name	AVERAGE PERCENT COVER		AVERAGE PERCENT COVER		AVERAGE PERCENT COVER
	MAY-AUG GRASSL - T2	Scientific Name	MAY-AUG FILLED - T2	Scientific Name	MAY-AUG OPEN - T2
<i>Distichlis spicata</i>	41.55	<i>Bassia</i> (dead)	10.62	<i>Cressa truxillensis</i>	10.24
Thatch	14.64	<i>Cressa truxillensis</i>	10.36	<i>Polypogon monspeliensis</i>	10.10
<i>Bromus diandrus</i>	13.79	<i>Atriplex</i> sp.	7.57	<i>Distichlis spicata</i>	9.28
<i>Hordeum leporinum</i>	7.52	<i>Polypogon monspeliensis</i>	6.54	<i>Bassia</i> (dead)	6.06
<i>Lactuca serriola</i>	4.76	<i>Distichlis spicata</i>	6.08	<i>Bromus diandrus</i>	3.38
<i>Rumex dentatus</i> spp. <i>klotzschianus</i>	3.85	<i>Bassia hyssopifolia</i>	5.82	<i>Atriplex</i> sp.	3.05
<i>Cressa truxillensis</i>	3.82	<i>Rumex dentatus</i> spp. <i>klotzschianus</i>	4.08	<i>Rumex dentatus</i> spp. <i>klotzschianus</i>	2.96
<i>Hordeum murinum</i> spp. <i>gussoneanum</i>	3.21	<i>Frankenia grandifolia</i> var. <i>campestris</i>	3.39	<i>Lactuca serriola</i>	2.57
		Thatch	2.94		

Scientific Name	AVERAGE PERCENT COVER		AVERAGE PERCENT COVER		AVERAGE PERCENT COVER
	MAY-AUG GRASSL - T3	Scientific Name	MAY-AUG FILLED - T3	Scientific Name	MAY-AUG OPEN - T3
<i>Distichlis spicata</i>	19.78	<i>Cressa truxillensis</i>	29.83		
<i>Bromus diandrus</i>	19.58	<i>Distichlis spicata</i>	20.28		
<i>Cressa truxillensis</i>	18.89	Thatch	11.17		
Thatch	17.00	<i>Bromus diandrus</i>	6.97		
<i>Distichlis</i> (thatch)	9.22	<i>Hordeum murinum</i> spp. <i>gussoneanum</i>	5.56		
<i>Frankenia grandifolia</i> var. <i>campestris</i>	4.44	<i>Meibomia</i> sp.	5.08		
<i>Lactuca serriola</i>	3.75	<i>Atriplex</i> sp.	3.00		
		<i>Lactuca serriola</i>	2.53		

Conclusions

Results of 1998 vegetation monitoring suggest that the Filled and Open habitat types at Kesterson were influenced by above normal precipitation and cooler temperatures. The prevalence of wetland species in many plots as compared to other annual species less likely to occur in wetlands is suggestive of their positive germination and growth response to these conditions. Vegetation types showed a delay in plant germination and growth (as evidenced by the large percent cover values for bare ground and standing water in all Trisections until the August sampling session). It is unknown at this time if the above normal precipitation will result in positive saltgrass growth and survival in Grassland habitats.

Results of the 1998 vegetation monitoring and results from previous monitoring years indicate that a wide range of plant species occupy a series of habitats that form a mosaic throughout Kesterson. Previously, three habitat types were broadly recognized (Filled, Open, and Grassland) within this mosaic; however, results of statistical analyses of vegetation and soils data over multiple years showed that these three created habitat types are not distinct from one another.

Therefore, these three habitat areas should be viewed only as convenient references for broad designation of vegetation. These categories are useful in viewing the successional patterns that occur within the disturbed habitat at Kesterson, but they are not useful as predictors of future vegetation. Also, the range of environmental parameters that control the vegetation structure and plant species composition is not fully known. Reclamation is currently exploring future vegetation monitoring programs.

The 1998 vegetation monitoring study indicates that a wide range of plant species occupy a series of habitats that form a mosaic throughout the study site. Based on the types of plant species that dominate the vegetation cover at the site, three main conclusions can be drawn: (1) the vegetation structure and plant species composition reflect the levels of disturbance and land use management of local areas; (2) the previously recognized three habitat types (Filled, Open, and Grassland) represent very generalized structural vegetation characterizations that do not fully reflect the structure and diversity of habitats at the site, but rather reflect the successional changes expected in disturbed habitats; and (3) the range of environmental parameters that control the vegetation structure and plant species composition are not fully known.

Disturbance and Land Use

The plant species composition, in terms of species diversity, is predominantly non-native annual herbs. These species occurred primarily in the more disturbed areas such as Filled sites. These Filled areas became an area of high disturbance as a result of the filling process and potential inclusion of a weedy plant species seed bank in the fill soil. The disturbance of the soil resulted in a potential release of plant nutrients and changed the water-holding capacity of the soil. The weedy annual species are adapted to those types of habitat conditions. Because of the large number of annual non-native "weedy" plant species established in the California flora, these disturbed areas generally become quickly dominated by these species. In contrast, the less disturbed sites had some dominant native

plant species such as saltgrass, which continue to dominate many of the Grassland areas. Many of the areas referred to as Open habitats are former cattail-dominated wetlands that were drained, and the vegetation thatch remains covering the ground. The thick thatch layer has remained over an extended period of time due to the lack of moisture for decomposition as a result of the drought conditions through 1993. These areas will most likely show the greatest change as the cattail thatch decomposes.

Habitat Types

Previously, three habitat types had been broadly recognized, namely, Filled areas, Grassland areas, and Open areas. It should be noted that these three types of habitats have been viewed as possibly artificial in terms of species composition and have been recognized as such in the Ecological Risk Assessment for Kesterson Reservoir (Ohlendorf and Santolo 1994, Santolo 1994). These three habitat areas should be viewed only as convenient references for broad designation. Future characterizations will need to look at the combination of local environmental parameters and types and levels of disturbance and land use, in combination with species associations, to provide a more useful habitat description. The preliminary characterization in the current monitoring report indicates that there are structural vegetation differences in the three recognized habitats, but a more detailed analysis of the plant species, environmental parameters, and wildlife use would provide a more functional perspective on habitat types and vegetation.

TABLE 6
Plant Species Included in All Figures of Vegetation Percent Cover for Dominant Plant Species

AMME	<i>Amsinckia menziesii</i> var. <i>intermedia</i>
ATRO	<i>Atriplex rosea</i>
ATSM	<i>Atriplex semibaccata</i>
AVBA	<i>Avena barbata</i>
BAHY	<i>Bassia hyssopifolia</i>
BRDI	<i>Bromus diandrus</i>
BRMO	<i>Bromus hordeaceus</i> (<i>B. mollis</i>)
BRRU	<i>Bromus madritensis</i> ssp. <i>rubens</i> (<i>B. rubens</i>)
BRKA	<i>Brassica kaber</i>
CRTR	<i>Cressa truxillensis</i>
DISP	<i>Distichlis spicata</i>
DITH	<i>Distichlis spicata</i> thatch
EPBR	<i>Epilobium brachycarpum</i>
FEMY	<i>Festuca myuros</i>
FRGR	<i>Frankenia salina</i> [<i>F. grandifolia</i>]
HECU	<i>Heliotropium curassavicum</i>
HORD	<i>Hordeum</i> sp.
HODE	<i>Hordeum depressum</i>
HOHY	<i>Hordeum marinum</i> ssp. <i>gussoneanum</i> (<i>H. hystrix</i>)

TABLE 6
Plant Species Included in All Figures of Vegetation Percent Cover for Dominant Plant Species

HOLE	<i>Hordeum murinum</i> ssp. <i>leporinum</i> (<i>H. leporinum</i>)
LASE	<i>Lactuca serriola</i>
LOMU	<i>Lolium multiflorum</i>
LUNA	<i>Lupinus nanus</i>
MEPO	<i>Medicago polymorpha</i>
MEIN	<i>Melilotus indica</i>
POAR	<i>Polygonum arenastrum</i> [<i>P. aviculare</i>]
POMO	<i>Polypogon monspeliensis</i>
RUDE	<i>Rumex dentatus</i>
SEVU	<i>Senecio vulgaris</i>
SEVE	<i>Sesuvium verrucosum</i>
MALE	<i>Malvella leprosa</i>
SOOL	<i>Sonchus oleraceus</i>
SPMA	<i>Spergularia marina</i>
SUMO	<i>Suaeda moquinii</i> [<i>S. fruticosa</i>]
DEAD	Dead plant material
BG	Bare ground

Twinspan Cluster Analyses of Species

Vegetation data from 1998 sampling rounds were analyzed using two-way indicator species analysis (TWINSPAN, Hill 1979). The data from all transects and sample rounds were combined to form a single data set for analysis, as was done with the 1993 vegetation data. In addition, the vegetation data sets for both years were limited only to the dominant plant species that comprised at least five percent of the cover in any Trisection during any of the three sample rounds.

The results of the species cluster analysis for the 1993 and 1998 data are shown in Figures 1 and 2, respectively. The TWINSPAN analysis groups species into categories based on similarities in cover percentages. The number of minor categories for the dominant species that resulted from the analyses was six in 1993 and four in 1998. The number of plant species comprising five percent or more of the plant cover decreased from 17 to 14 in this same period.

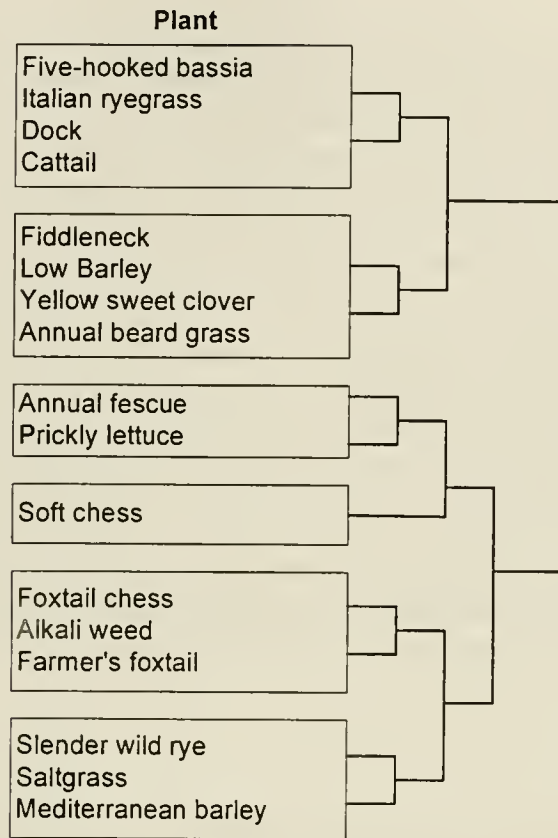


FIGURE 1
Twinspan Analysis of Plant Species - 1993

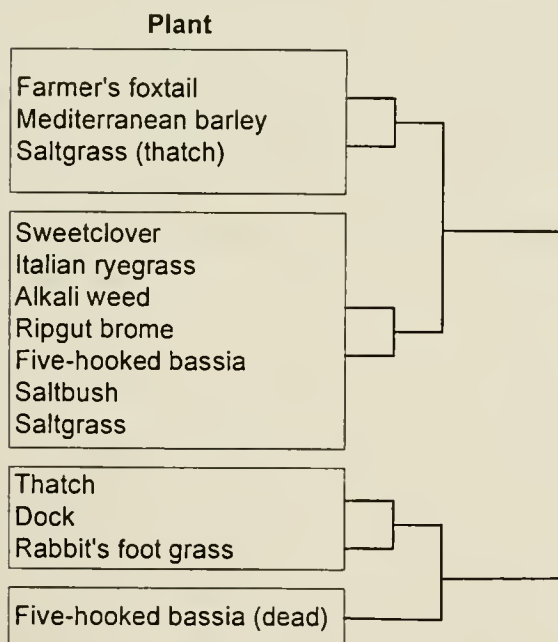


FIGURE 2
Twinspan Analysis of Plant Species - 1998

Comparison of Figures 1 and 2 shows relatively minor changes in the associations of the types of plants that dominate ground cover. The most notable exceptions are that certain native grass species (soft chess, low barley, and slender wild rye) appear to have dropped out. These species appear to have been predominantly replaced with higher proportions of species previously observed. One factor that adds to the uncertainty of the comparisons is the fact that fewer sample plots were available for analysis in 1998 than in 1993, especially in Trisection 3 where annual grasses have dominated in past years.

Twinspan cluster analysis of samples using the 1998 data indicated that nearly every category was comprised of samples from all habitat types in each Trisection. This implies that vegetative associations between 1993 and 1998 have changed in such a way that TWINSpan cluster analysis no longer shows a clear separations of these habitat types. This is logical in that the habitat types used in the study were actually reflective of different land management areas rather than actual habitat types. As more time elapsed from the time that clearing, dewatering, or filling occurred, it is expected that each of these types would become more similar in vegetative composition to the other areas. These changes in floristic composition reflect how soil and hydrologic conditions have been made more uniform over the entire Kesterson site and how the different plant species compete for space and growing factors over time.

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3. Selenium in Soil and Detritus

Introduction

The level and distribution of selenium in the soil, especially in the top 15 cm of water-extractable soil selenium, relate to selenium found in plants and, therefore available to wildlife that feed on plants (Wahl et al. 1994). This relationship between selenium in the soil and plant selenium is highly variable although the slope is significant (Ohlendorf and Santolo 1994, Santolo 1994). Selenium concentrations measured in soil vary from year-to-year and among the sampling locations. Some of this variability may be due to vegetation type at the sample location, soil parent type, rainfall prior to sampling, and other factors.

Selenium levels in the detritus pathway (i.e., plant litter, mushrooms, and sowbugs) show some of the highest potential risk in terms of elevated selenium. More plant biomass dies and is shed as litter than is consumed alive (Swift et al. 1979) making this an important pathway for the movement of biologically incorporated selenium. For this reason, more bioavailable selenium may reside in decomposers and in fresh or partially decomposed organic matter than in live plants or their consumers. Selenium, similar to other nutrients and trace elements such as nitrogen, phosphorus, and calcium, is recycled within the ecosystem. Plants and animals associated with detritus may obtain selenium as it cycles through the system and may also acquire additional selenium moving up from below the root zone. Decomposing organic matter below the surface at Kesterson may also contribute to selenium in decomposers such as mushrooms and soil microbes.

Objectives

The objective of the soil and detritus sampling program was to determine the selenium available from soil and the accumulation in the detritus layer at Kesterson and compare these results with those from other years.

Methods

Soil

Soil samples were collected at each sample station by inserting a 2.54-cm corer about 15cm into the soil and a 4-cm corer was used to collect soil from 15 to 50cm and from 50-100cm. Duplicate cores were collected at each site within a radius of about 1m of the station center. Soil samples were analyzed by Lawrence Berkeley Laboratory (LBL) for total selenium and water-extractable selenium. The extracts used in the total water extractable selenium analysis were made using a 5:1 water to dry-mass ratio following procedures described in previous progress reports by LBL.

Detritus

Detritus samples were collected during September at each of 54 sample stations by separating the organic layer of material from the mineral soils. This was accomplished by removing the loose top layer of material (i.e., loose plant material and other debris) by hand before the soil sample was taken. Each sample consisted of a composite of three samples collected within a radius of about 8m (24ft) from the station's center. Samples were analyzed by Laboratory for Environmental Testing, Inc. (LET) for total selenium.

Results

Soil

Spatial Distribution of Selenium in Soil

Total soil selenium and water-extractable soil selenium from soil collected in 1998 are compared spatially, by trisection, and by habitat type in Table 1. As in previous years, selenium concentrations were generally highest in Trisection 1 and in Open habitat types. Selenium concentrations in total soil selenium were significantly higher in Open and Grassland habitats than in Filled habitat samples and concentrations in Open habitats were higher than in Grassland habitats. In the water-extractable fraction, selenium was significantly higher in Open habitats than either Grassland or Filled, which were not statistically different.

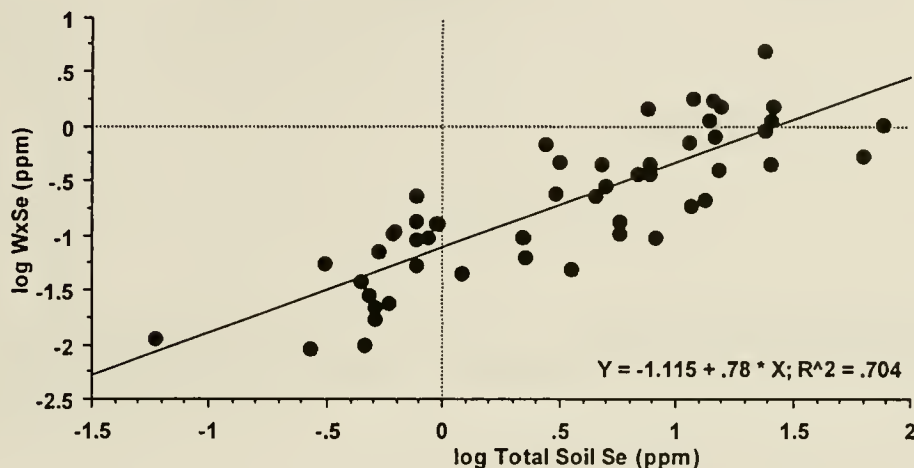
TABLE 1

Total and Water-extractable Soil Selenium Concentrations (ppm dry weight.) at Kesterson, 1998

Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	GM	n	Range	GM	n	Range	GM	n	Range	GM	n	Range
Total Soil Selenium												
Grassland	9.7	6	5.7 – 26	0.94	6	0.46 – 3.5	2.4	4	0.78 – 6.8	2.8	16	0.46 – 26
Filled	0.81	6	0.61 – 0.96	0.83	6	0.60 – 4.7	0.58	6	0.27 – 3.2	0.73	18	0.60 – 4.7
Open	17	6	4.5 – 77	16	6	7.6 – 26	14	6	7.5 – 26	15	18	4.5 – 77
Kesterson Total	5.1	18	0.60 – 77	2.3	18	0.60 – 26	2.7	16	0.27 – 26	3.2	52	0.60 – 77
Water-extractable Soil Selenium												
Grassland	0.27	6	0.11 – 0.69	0.037	6	0.010 – 0.13	0.19	4	0.052 – 0.69	0.12	16	0.010 – 0.69
Filled	0.12	6	.092 – 0.23	0.067	6	0.011 – 0.44	0.050	6	0.009 – 0.47	0.074	18	0.009 – 0.47
Open	0.61	6	0.23 – 1.7	0.64	6	0.21 – 1.5	1.1	6	0.095 – 4.9	0.75	18	0.095 – 4.9
Kesterson Total	0.27	18	0.92 – 1.7	0.12	18	0.010 – 1.5	0.22	16	0.009 – 4.9	0.19	52	0.009 – 4.9

The water-extractable fraction of selenium in the soil is the selenium that is mobile and available for plant uptake (Wahl et al. 1994). Selenium concentrations showed a strong relationship between total soil selenium and the water-extractable fraction (Figure 1).

FIGURE 1
Relationship of Total Soil Selenium to Water-extractable (WxSe) Selenium



Temporal Distribution of Selenium in Soil

There were no significant differences found among years for either total or water-extractable selenium concentrations (Table 2). Until 1995, soil samples were generally collected at the same time vegetation was collected (March – May). From 1995 to 1998, soil samples were collected in August – September.

TABLE 2
Se Concentrations (ppm dry weight) of Soil Selenium from Kesterson Reservoir

Year	n	Range	Geometric Mean ^a	Comments
Total Soil selenium				
1989	50	0.40 – 31	3.9	Post filling of Kesterson
1990	52	0.30 – 35	2.7	
1991	52	0.30 – 31	2.9	
1992	53	0.14 – 156	2.3	
1993	54	0.26 – 73	3.9	Heavy March rain
1994	54	0.17 – 42	2.3	
1995	49	0.29 – 229	4.6	
1996	53	0.33 – 148	3.5	
1998	52	0.60 – 77	3.2	Ephemeral pools late into the summer
Water-extractable Soil Selenium				
1989	54	0.004 – 2.2	0.17	Post filling of Kesterson
1990	53	0.006 – 2.1	0.12	

TABLE 2

Se Concentrations (ppm dry weight) of Soil Selenium from Kesterson Reservoir

Year	<i>n</i>	Range	Geometric Mean ^a	Comments
1991	54	0.002 – 2.7	0.19	
1992	53	0.004 – 1.6	0.091	
1993	54	0.006 – 0.62	0.11	Heavy March rain
1994	54	0.006 – 2.9	0.18	
1995	49	0.006 – 2.5	0.19	
1996	53	0.010 – 2.1	0.17	
1998	52	0.009 – 4.9	0.19	Ephemeral pools late into the summer

^aThere was no significant difference in Se concentrations among years for either total or water-extractable selenium (Tukey-Kramer HSD $P \leq 0.05$).

Detritus

Spatial Distribution of Selenium in Detritus

Selenium concentrations in detritus samples collected in 1998 are compared by trisection and by habitat type in Table 3. Mean selenium concentrations in detritus samples collected from Open habitats were significantly higher than concentrations in samples from the other habitats. Selenium concentrations in detritus were not significantly different among trisections.

TABLE 3

Selenium Concentrations (ppm dry weight) in Detritus Samples, 1998

	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
Habitat Type	GM	<i>n</i>	Range	GM	<i>n</i>	Range	GM	<i>n</i>	Range	GM	<i>n</i>	Range
Grassland	15	6	4.4 – 37	5.4	6	1.3 – 18	5.2	5	2.4 – 10	7.6	17	1.3 – 37
Filled	12	6	5.4 – 26	13	5	6.2 – 49	2.5	6	1.2 – 5.7	7.2	17	1.2 – 49
Open	119	6	19 – 280	190	6	58 – 620	76	6	22 – 170	120	18	19 – 620
Kesterson Total	28	18	4.4 – 280	25	17	1.3 – 620	10	17	1.2 – 170	19	52	1.2 – 620

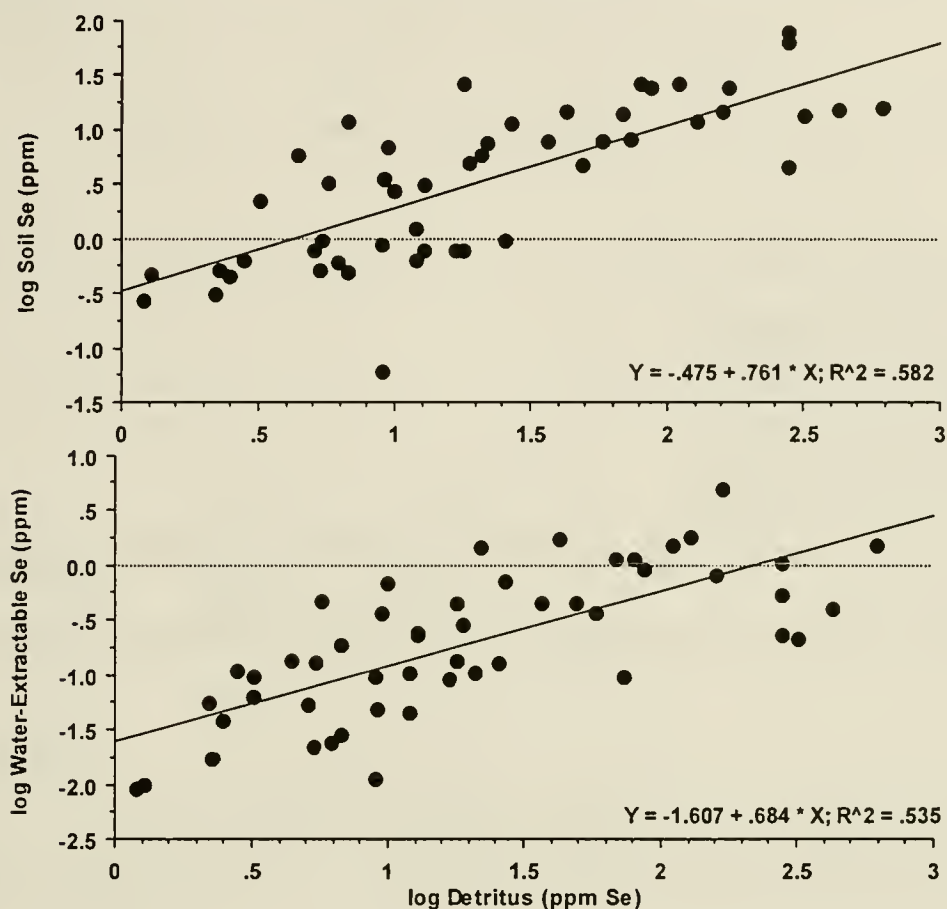
Soil Selenium and Detritus

Edaphic, climatic, and other factors account for much of the variability between detritus selenium and soil selenium. Plants take up available selenium from the soil and as those plants and the animals that feed on them die they fall to the ground and become the detritus layer on top of the soil. As the detritus breaks down it moves into the soil and the top 15cm of soil includes organic matter and the selenium associated with it. There was a strong, positive relationship with both total soil selenium and water-extractable selenium levels and

detritus selenium levels in 1998 samples (Figure 2) reflecting the strong association between soil and detritus selenium.

FIGURE 2

Relationship Between Selenium in Detritus and Total and Water-Extractable Soil Selenium.



Temporal Distribution of Selenium in Detritus

Selenium levels in detritus from Open habitat was highly variable among years ranging from 7.1 to 620 ppm and they were not significantly different among the years that samples were collected (Table 4). Levels of selenium from Other habitats (i.e., Grassland habitats in 1988 and Grassland and Filled habitats combined in 1996 – 1998) were significantly higher in 1988 than the other years sampled (Table 4).

TABLE 4
Se Concentrations (ppm dry wt) in Detritus Samples, 1988 – 1998

Year - Habitat	n	Range	Geometric Mean Se	Notes
Open Habitat				
1988	9	67 - 317	140 A	
1996	18	7.1 - 340	66 A	
1997	18	9.2 - 340	54 A	
1998	18	19 – 620	120 A	
Other Habitat				
1988	33	8.0 - 170	55 a	No detritus in Filled habitat
1996	36	1.0 - 22	4.8 b	No difference between Filled and Grassland
1997	36	0.89 - 130	5.2 b	No difference between Filled and Grassland
1998	33	1.2 – 49	7.3 b	No difference between Filled and Grassland

Note: Geometric mean concentrations within Open habitats not sharing the same capital letter are significantly different ($P \leq 0.05$).

Geometric mean concentrations within Other habitats not sharing the same lower case letter are significantly different ($P \leq 0.05$).

Discussion

Generally, soil selenium concentrations are poor indicators of how much selenium is available to plants (NIWQP 1998, Ohlendorf and Santolo 1994, Santolo 1994). However, in 1998 plant selenium in samples was strongly correlated to water-extractable soil selenium (see Section 4; Selenium in Plants).

Selenium concentrations in detritus were similar among years in Open habitats and have significantly declined in Grassland and Filled habitats from 55 ppm to 7.3 ppm at Kesterson (Table 4; Grassland and Filled Habitats were not significantly different between Grassland and Filled habitats in 1996 – 1998 and were combined within each year as “Other”). In Open habitats, where a large amount of detritus was left on the soil surface by cutting and disking cattails and other vegetation, selenium concentrations have remained high and continue to be significantly higher than selenium concentrations in Grassland and Filled habitats. However, Open habitat covers about 13 percent of Kesterson, less than either Filled or Grassland habitats (Figure 1), and vegetation in these habitats is becoming more alike as succession continues (Ohlendorf and Santolo 1994, USBR 1995). Also, Kesterson is a relatively small area (about 517ha) in a larger mosaic of uncontaminated grasslands and wetlands (Figure 3). Therefore, wildlife feeding at Kesterson are likely to use Open habitats to a lesser extent than Filled and Grassland habitats and, depending on home range of a species, are likely to forage off-site to a great extent.

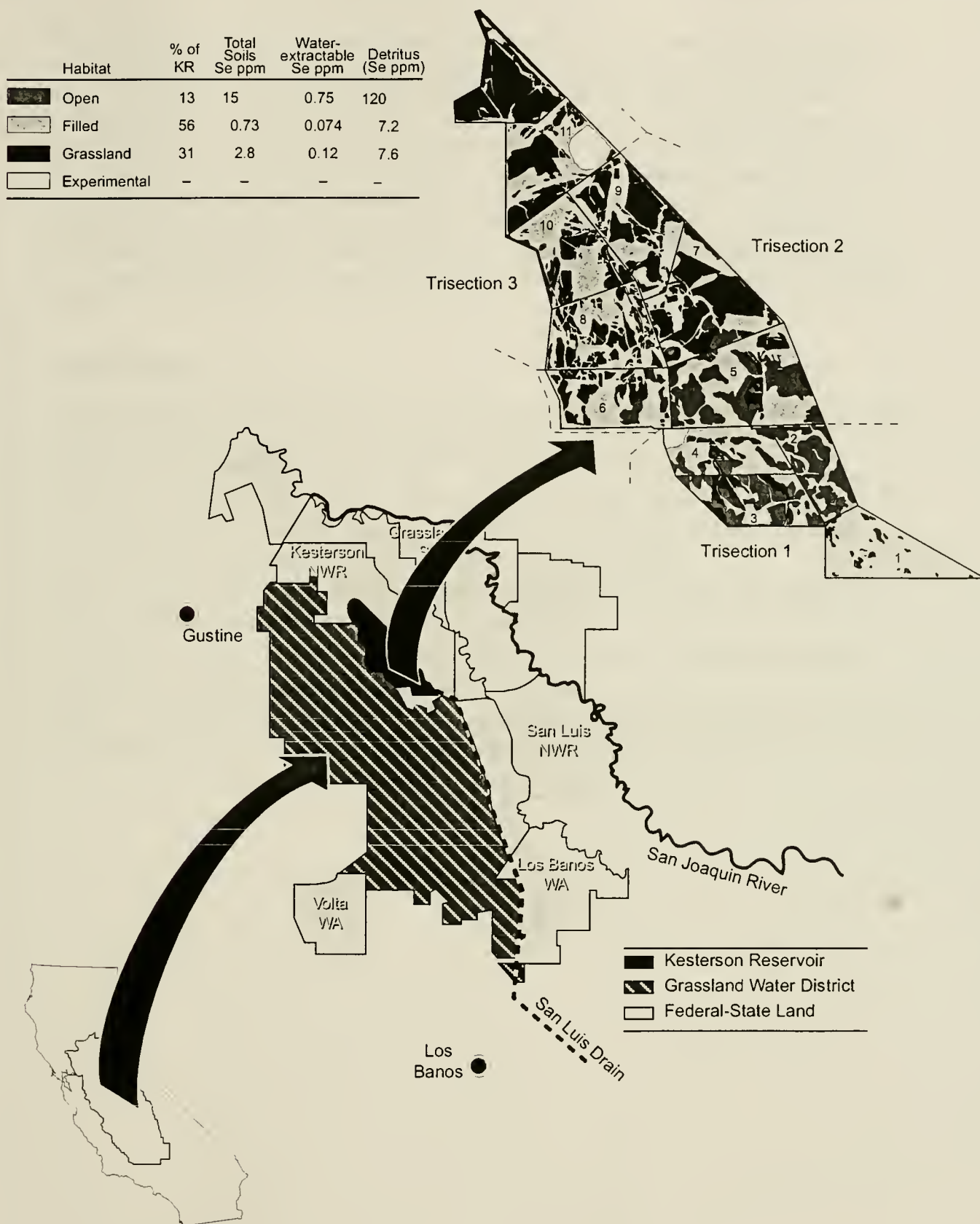


Figure 3
Kesterson Location and Habitats

Since filling, the detritus and decomposers have contained the highest levels of selenium among biotic and abiotic samples characterized for potential risk to wildlife at Kesterson. However, exposure of wildlife to selenium along this pathway may be low because of limited feeding on detritus, mushrooms, and detritivores. Stomach contents of birds and mammals that have been examined have contained only trace amounts of mushrooms and no sowbugs have been found. As in other recent years, few mushrooms were found growing at Kesterson, further reducing the risk of selenium exposure through this pathway. Sowbugs, which have not been collected since 1995, were only found in low numbers during the sampling period probably because of the unusual conditions at Kesterson in 1998 (i.e., ephemeral pools covered most of Kesterson during most of the invertebrate sampling period).

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4. Selenium in Plants

Introduction

The level of selenium contamination found in plants, and therefore available to wildlife that feed on plants, is important for assessing the potential risk to wildlife at Kesterson. Although selenium concentrations measured in plants vary from year-to-year, plant selenium levels have not changed significantly since 1991.

Since Kesterson was dewatered and filled in 1988, plants have been monitored from the same sampling locations. Plant sampling in 1988 occurred before and during the filling operation and plants from 1988 were only found in Grassland habitats. Plant species that dominated throughout Kesterson were originally chosen for sampling on the basis of presampling discussions with Service personnel. Plant species collected in 1998 included many of those that have been collected in previous sampling years. These are plants that are expected to continue to be components of plant communities that occur at Kesterson and are important forage for wildlife at Kesterson, and those selected as a result of the 1993 Risk Assessment (Ohlendorf and Santolo 1994, Santolo 1994). Plant species that were chosen for collection in 1998 were saltgrass, perennial bunchgrass (*Sporobolus* sp.), perennial saltbush, alkali weed, filaree, bassia, prickly lettuce, clover, and annual grass. These plants represent four plant types based on ecological considerations (Grasses, Transitional Annuals, Persistent Annuals, and Perennials) that are expected to continue to be important components of the plant community at Kesterson into the future. Grasses have been further divided into annual and perennial species (i.e., Annual Grasses and Perennial Grasses). In selecting the groupings of plants, root depth was originally considered as one of the criteria. However, there was no clear relationship between root depth and plant selenium concentration, and for some species the depth of the root system was not known. Thus, the ecological grouping resulted in more homogeneous sets of plants that reflected similar selenium concentrations and expected occurrence through plant succession in the future (Ohlendorf and Santolo 1994).

Objectives

The primary objective of the vegetation sampling program was to determine the selenium concentrations in plants to indicate the level of selenium available to wildlife in abundant vegetation at Kesterson.

Methods

Plant samples were collected from six stations in each habitat type that occurred within each trisection during the peak periods of growth for the individual plant species. These growth periods corresponded to the overwintering period for birds from mid-December to March and the reproductive period for birds from March to July. Sampling times were determined by the weather, plant growth peaks, and by wildlife use of Kesterson.

Above-ground plant material was collected by clipping sections from living plants with shears or by pinching sections off with fingers. Samples were collected from at least three different plants within an 8-meter radius of the station to provide a minimum of 2 grams (wet weight) of vegetative material.

Selenium Analysis

Samples were stored at -20° C, then shipped to a commercial laboratory (Environmental Trace Substances Research Center, Columbia, Missouri) from 1987 to 1991. After 1991, samples were shipped to Laboratory and Environmental Testing (Columbia, Missouri). All samples were kept frozen and then shipped on dry ice for total selenium analysis.

Results

Selenium concentrations in plants collected in 1998 were highly variable, ranging from 1.2 ppm in bunchgrass to 8.8 ppm in mustard and the differences were not significantly different among species (Table 1). Annual Grasses had significantly higher selenium concentrations than Perennial Grasses and Transitional Annuals had higher selenium concentrations than both Perennial Shrubs and Grasses. Plants collected from Trisection 1 had significantly higher selenium concentrations than those from Trisection 2 but they were not significantly higher than plants collected in Trisection 3 (Fig 1 A). Selenium concentrations in plants collected from Open habitats had significantly higher selenium concentrations than those from Grassland and Filled habitats (Figure 1B). The two highest samples were annual grass samples from Open habitat in the southeast corner of Trisection 3.

FIGURE 1

Box Plots of Selenium Concentrations Among Trisections (A) and Habitat Types (B). The Bars from the bottom up are the 10th, 25th, 50th, 75th, and 90th percentiles, the circles are outliers.

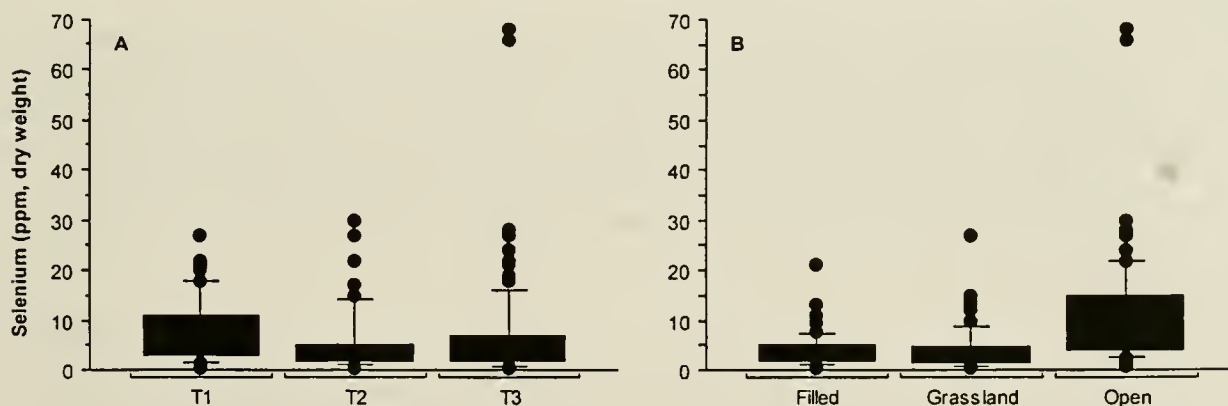


TABLE 1
Summary of Se Concentrations (ppm dry weight) in Plants Collected from Kesterson, 1998

Species	<i>n</i>	Geometric Mean ^{a,b}	Range
Persistent Annuals	107	3.6 A,B,C	0.20 – 27
Alkali Weed	34	3.6	0.20 – 15
Filaree	13	3.5	0.80 – 15
Clover	34	3.6	0.50 – 27
Transitional Annuals	52	4.9 A	0.60 – 27
Mustard	7	8.8	1.2 – 27
Bassia	30	4.9	1.5 – 21
Prickly Lettuce	41	3.8	0.20 – 27
Annual Grass	44	4.6 A,B	0.50 – 68
Annual Grass	44	4.6	0.50 – 68
Perennial Shrubs	6	1.8 C	0.30 – 14
Saltbush	6	1.8	0.30 – 14
Perennial Grasses	31	2.4 B,C	0.30 – 13
Saltgrass	28	2.6	0.30 – 13
Bunchgrass	3	1.2	0.64 – 2.0
All Plants	240	3.8	0.20 – 68

^a There was no significant difference in Se concentrations among species in 1998 (Tukey-Kramer HSD $P \leq 0.05$).

^b Plant Groups sharing the same upper case letter are not significantly different (Tukey-Kramer HSD $P \leq 0.05$).

All statistical comparisons were made using geometric means (GM) because selenium concentrations are not normally distributed and show a positive skew of the data. For looking at yearly comparisons, all years were compared to 1998, differences among other years have been reported in previous reports and are not addressed here. Arithmetic means ($\bar{x}$) and standard deviations ($\pm$ SD) were used to show annual trends and they show the same trends as GMs, however, the arithmetic means are generally higher than geometric means.

Persistent Annuals

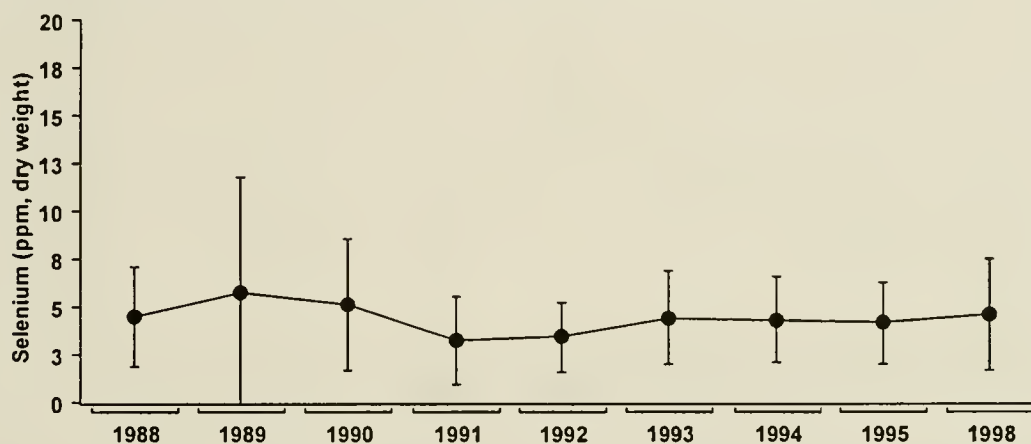
- **Alkali Weed** is a low, branched perennial herb with gray, tufted, woolly stems and leaves. It is found from along the seacoast in saline and alkaline places to areas throughout most of cismontane California below 1,200m (Munz and Keck 1973). At Kesterson, alkali weed grows in all three habitat types. It is usually found in small patches in Grassland and Open habitats and in larger patches in Filled habitat. Selenium varied both spatially (by Trisection) and by habitat (Table 2) but it varied significantly only among trisections: selenium was higher in alkali weed collected from Trisection 1

than the other trisections. Alkali weed selenium levels did not differ significantly among the years samples were collected (Figure 2).

TABLE 2
Selenium Concentrations (ppm dry weight) in Alkali Weed, 1998

Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	GM	n	Range	GM	n	Range	GM	n	Range	GM	n	Range
Grassland	5.2	4	2.2 – 15	1.1	4	0.20 – 2.9	2.9	5	0.40 – 7.3	2.6	13	0.02 – 15
Filled	7.2	3	5.3 – 9.3	4.0	2	3.2 – 5.0	3.3	6	1.5 – 7.1	4.2	11	1.5 – 9.3
Open	4.5	2	4.2 – 4.9	4.1	2	2.5 – 6.8	4.9	6	2.8 – 9.0	4.7	10	2.5 – 9.0
Kesterson Total	5.6	9	2.2 – 15	2.2	8	0.20 – 6.8	3.7	17	0.40 – 9.0	3.6	34	0.20 – 15

FIGURE 2
Selenium Concentrations in Alkali Weed ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1988 (before filling) – 1998.

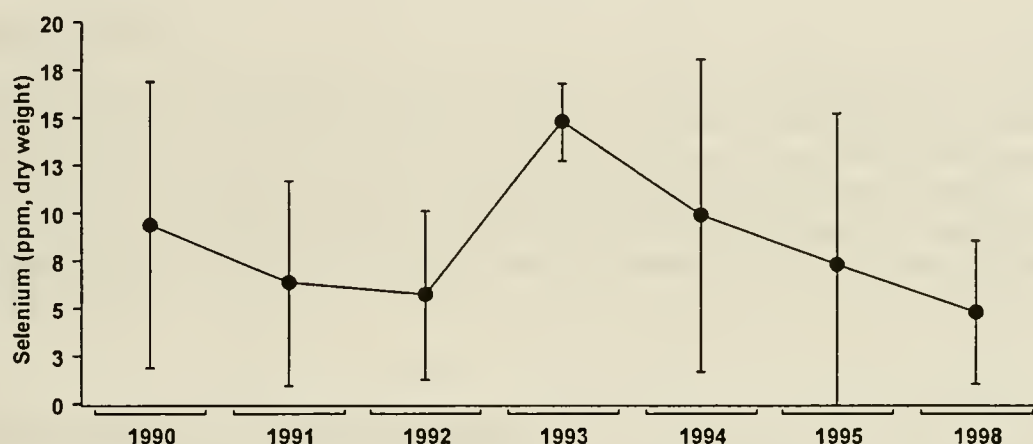


- Filaree, a plant introduced from the Mediterranean region, has become a widespread annual forb at Kesterson. It is highly regarded as a forage plant in California (Robbins et al. 1970, Munz and Keck 1973). Few filaree plants were found growing at the site in 1993, possibly due to the dry conditions and selenium levels were relatively high in these samples (GM = 15 ppm, n = 4, Range = 13 – 17 ppm). Filaree has been fairly abundant since 1993 but in 1998 open water over much of Kesterson delayed growth of many plants and few filaree were found during the sample period. Filaree collected in 1998 was not different from filaree collected from 1990 to 1995 (Figure 3). Selenium concentrations in the samples collected varied from 0.80 to 15 ppm but concentrations were not significantly different among trisections or habitats (Table 3).

TABLE 3
Selenium Concentrations (ppm dry weight) in Filaree, 1998

Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	GM	n	Range	GM	n	Range	GM	n	Range	GM	n	Range
Grassland	6.4	2	5.9 – 6.9	1.4	2	1.0 – 2.0	2.5	3	0.80 – 4.7	2.8	7	0.80 – 6.9
Filled	5.3	1					3.4	4	1.2 – 7.1	3.7	5	1.2 – 7.1
Open							15	1		15	1	
Kesterson Total	5.9	3	5.3 – 6.9	1.4	2	1.0 – 2.0	3.6	8	0.80 – 15	3.5	13	0.80 – 15

FIGURE 3
Selenium Concentrations in Filaree ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1990 – 1998.



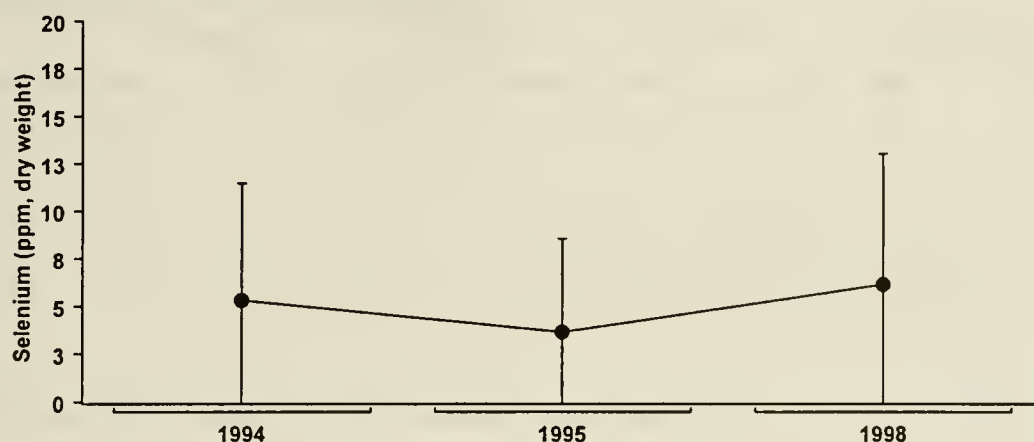
- Clover (*Trifolium* or true clover and *Medicago*) is an annual plant in the pea family that can grow to about 0.5m and is valued as forage. Clover is found throughout the site, in all habitat types. Selenium concentrations in clover varied from 0.50 to 27 ppm (Table 4) but were not significantly different among trisections or habitats at Kesterson. Clover in 1998 had a geometric mean selenium concentration of 3.6 ppm that was not significantly different from concentrations found in samples from 1994 and 1995 (Figure 4)

TABLE 4
Selenium Concentrations (ppm dry weight) in Clover, 1998

Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	GM	n	Range	GM	n	Range	GM	n	Range	GM	n	Range
Grassland	5.3	5	2.3 – 27	2.6	7	0.87 – 5.2	1.1	3	0.65 – 2.0	2.8	15	0.65 – 27
Filled	3.6	2	1.8 – 7.1	2.1	3	1.2 – 3.5	1.8	5	0.50 – 6.9	2.1	10	0.50 – 7.1
Open	14	3	9.1 – 18	7.5	3	2.2 – 15	9.3	3	3.0 – 24	10	9	2.2 – 24
Kesterson Total	6.6	10	1.8 – 27	3.2	13	0.87 – 15	2.4	11	0.50 – 24	3.6	34	0.50 – 27

FIGURE 4

Selenium Concentrations in Clover ($\bar{x}$, ± 1 SE) Collected at Kesterson, 1994 – 1998.



Transitional Annuals

- **Mustard** is an invasive species at Kesterson that is related to many important vegetables including cabbage, cauliflower, and broccoli as well as many weeds such as pepperweed and field cress. Mustard seeds can be dormant for forty years and, after a rainy season, can germinate in spring (Vessel and Wong 1987). The wet conditions at Kesterson prevented mustard from growing in many areas that it has been found in past years and selenium concentrations were not significantly different among the samples collected in 1998 (Table 5).

TABLE 5

Selenium Concentrations (ppm dry weight) in Mustard, 1998

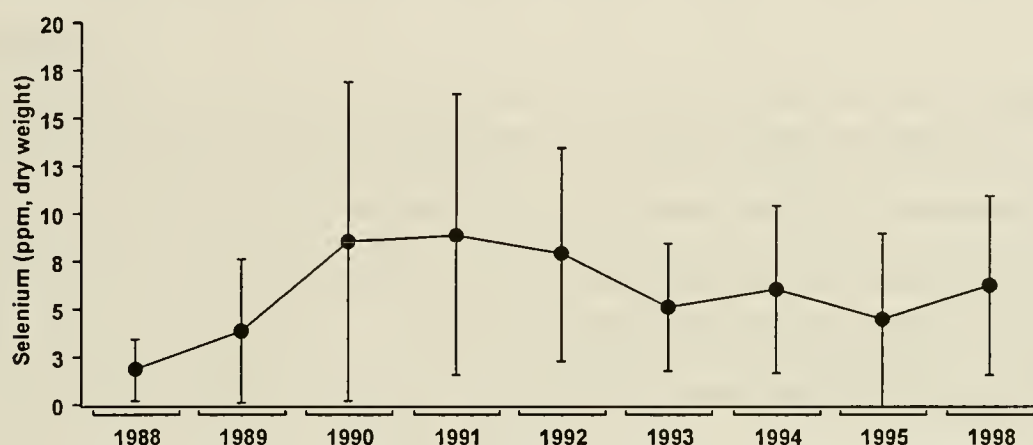
Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	GM	n	Range	GM	n	Range	GM	n	Range	GM	n	Range
Grassland							13	1		13	1	
Filled							3.6	3	1.2 – 9.3	3.6	3	1.2 – 9.3
Open				13	1		23	2	19 – 27	19	3	13 – 27
Kesterson Total				13	1		8.2	6	1.2 – 27	8.8	7	1.2 – 27

- **Bassia** is a densely leafed annual plant. It grows to about 1.8m and is a weed at scattered areas below 300m elevation (Munz and Keck 1973). Bassia is found in all habitat types at Kesterson. Selenium concentrations ranged from 1.5 to 21 ppm (Table 6). Mean selenium in bassia was not significantly different among trisections or habitats in samples collected during 1998. When compared to selenium levels from other years, selenium in bassia collected in 1998 was significantly higher than that found in bassia collected in 1988 and 1989 (Figure 5).

TABLE 6
Selenium Concentrations (ppm dry weight) in Bassia, 1998

Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	GM	n	Range	GM	n	Range	GM	n	Range	GM	n	Range
Grassland	2.2	1		3.3	1					2.7	2	2.2 – 3.3
Filled	6.6	5	1.9 – 21	6.9	3	3.8 – 13	3.7	2	2.7 – 5.2	5.9	10	1.9 – 21
Open	5.7	6	1.5 – 14	4.6	6	2.5 – 11	4.3	6	2.6 – 7.8	4.8	18	1.5 – 14
Kesterson Total	5.6	12	1.5 – 21	5.0	10	2.5 – 13	4.1	8	2.6 – 7.8	4.9	30	1.5 – 21

FIGURE 5
Selenium Concentrations in Bassia ($\bar{x}$, $\pm$ 1 SD) Collected at Kesterson, 1988 – 1998.



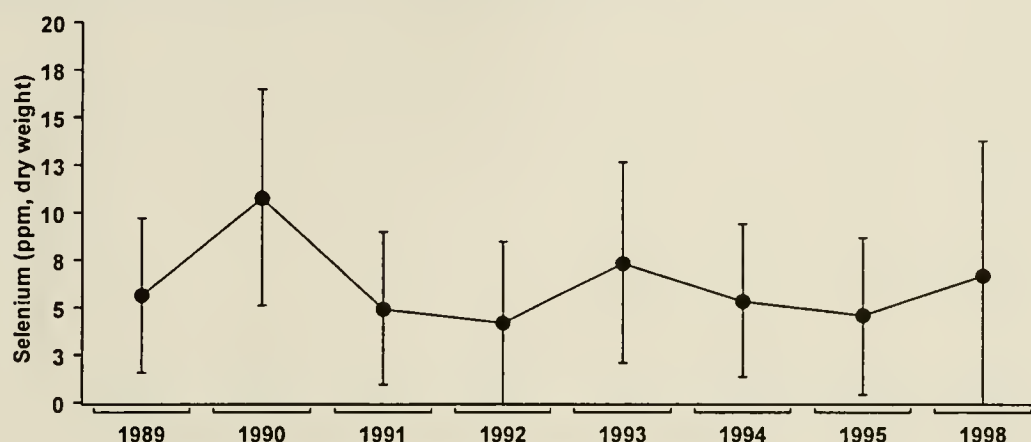
- **Prickly Lettuce** is an erect annual or biannual herb introduced from Europe and common throughout California (Robbins et al. 1970). Selenium in prickly lettuce ranged from 0.20 to 27 ppm (Table 7). Selenium was not significantly different in prickly lettuce compared by trisection but samples from Open habitat had significantly higher concentrations than those samples from Grassland and Filled habitats. Selenium in prickly lettuce collected in 1998 was significantly lower than that in prickly lettuce samples from 1990 (Figure 6).

TABLE 7
Selenium Concentrations (ppm dry weight) in Prickly Lettuce, 1998

Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	GM	n	Range	GM	n	Range	GM	n	Range	GM	n	Range
Grassland	3.9	6	2.2 – 14	2.1	6	0.61 – 5.9	2.5	5	0.50 – 10	2.8	17	0.50 – 14
Filled	0.72	2	0.20 – 2.6	1.6	3	1.1 – 3.5	1.7	5	0.60 – 3.2	1.4	10	0.20 – 3.5
Open	8.3	4	3.4 – 14	13	6	3.2 – 27	10	4	2.7 – 22	11	14	2.7 – 27
Kesterson Total	3.8	12	0.20 – 14	4.2	15	0.61 – 27	3.3	14	0.50 – 22	3.8	41	0.20 – 27

FIGURE 6

Selenium Concentrations in Prickly Lettuce ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1989 – 1998.



Annual Grass

- The grass family (Gramineae) includes 4,500 species of perennial and annual grasses, introduced from all over the world, that grow in California (Munz and Keck 1973). Winter annual grasses such as oats, brome, and fescue are common to Kesterson. These plants require winter and spring rains, with a cool growing period for germination; they die during the hot, rainless summer (Crampton 1974). Selenium varied greatly in grasses collected in 1998, ranging from 0.50 to 68 ppm (Table 8). Selenium in annual grass collected from Open habitats was significantly higher than that in Grassland and Filled habitats. Annual Grass selenium was not significantly different among trisections. There were no significant differences between selenium in Annual Grass collected in 1998 and that in Annual Grass from other years (Figure 7).

TABLE 8

Selenium Concentrations (ppm dry weight) in Annual Grass, 1998

Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	GM	n	Range	GM	n	Range	GM	n	Range	GM	n	Range
Grassland	3.1	5	1.6 – 5.2	1.5	5	0.85 – 3.1	2.5	4	1.0 – 6.5	2.3	14	0.85 – 6.5
Filled	4.6	5	3.1 – 11	2.4	4	1.3 – 4.2	1.0	4	0.50 – 2.9	2.4	13	0.50 – 11
Open	9.4	7	0.81 – 22	11	5	4.2 – 30	27	5	6.5 – 68	14	17	0.81 – 68
Kesterson Total	5.5	17	0.81 – 22	3.6	14	0.85 – 30	4.8	13	0.50 – 68	4.6	44	0.50 – 68

FIGURE 7

Selenium Concentrations in Annual Grass ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1989 – 1998.



Perennial Shrubs

- **Saltbush.** Perennial saltbush is a widespread erect shrub that grows to 1 to 3m in height (Munz and Keck 1973). There are very few perennial saltbushes growing at Kesterson and many of those appear to be decadent and not regenerating. These bushes are heavily utilized by songbirds (including loggerhead shrikes) for shelter, nesting, and foraging. Too few samples were collected for comparison among trisections or habitats (Table 9).

TABLE 9

Selenium Concentrations (ppm dry weight) in Saltbush, 1998

Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	GM	n	Range	GM	n	Range	GM	n	Range	GM	n	Range
Grassland	2.3	3	0.68 – 14	0.30	1		12	1		2.1	5	0.30 – 14
Filled												
Open	0.89	1								0.89	1	
Kesterson Total	1.8	4	0.68 – 14	0.30	1		12	1		1.8	6	0.30 – 14

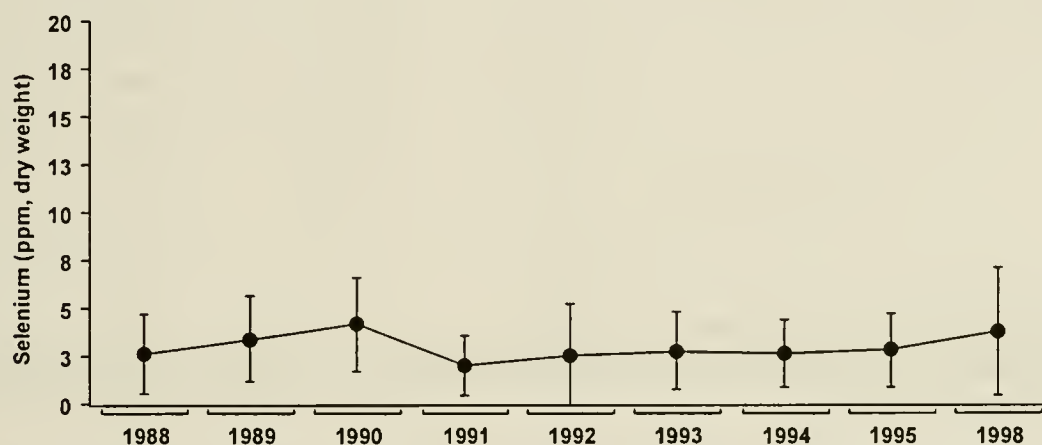
Perennial Grass

- **Saltgrass** is a low perennial that can spread by seed or by its rootstocks (Robbins et al. 1970, Munz and Keck 1973). Selenium in saltgrass collected in 1998 ranged from 0.30 to 13 ppm (Table 10). There was no difference in selenium concentration in saltgrass compared by trisection or by habitat. There were no significant differences between selenium in saltgrass collected in 1998 and that in saltgrass from other years (Figure 8).

TABLE 10
Selenium Concentrations (ppm dry weight) in Saltgrass, 1998

Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	GM	n	Range	GM	n	Range	GM	n	Range	GM	n	Range
Grassland	3.3	6	1.4 – 12	1.4	6	0.50 – 3.0	1.9	6	0.30 – 13	2.1	18	0.30 – 13
Filled				2.1	1		2.1	3	1.3 – 3.6	2.1	4	1.3 – 3.6
Open	4.0	1		5.0	1		6.2	4	5.5 – 7.0	5.5	6	4.0 – 7.0
Kesterson Total	3.4	7	1.4 – 12	1.7	8	0.50 – 5.0	2.8	13	0.30 – 13	2.6	28	0.30 – 13

FIGURE 8
Selenium Concentrations in Saltgrass ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1988 – 1998.



- **Bunchgrasses** are native perennial grasses that are part of the alkali grassland community that historically occurred at Kesterson (Bittman 1985). The bunchgrasses are found in only a small part of Kesterson and, therefore, only a few samples were collected. Selenium concentrations were low in the three samples that were collected (Table 11).

TABLE 11
Selenium Concentrations (ppm dry weight) in Bunchgrass, 1998

Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	GM	n	Range	GM	n	Range	GM	n	Range	GM	n	Range
Grassland				1.7	2	1.5 – 2.0	0.64	1		1.2	3	0.64 – 2.0
Filled												
Open												
Kesterson Total				1.7	2	1.5 – 2.0	0.64	1		1.2	3	0.64 – 2.0

Selenium Concentrations in Plants Over Time

Selenium concentrations in plants collected in 1998 were significantly higher than plants collected in 1988. However, in 1988, terrestrial plants were only found in Grassland habitat and if selenium from plants collected in Grassland habitat (2.5 ppm) is compared to 1988 samples there is no significant difference found. Selenium in plants collected in 1998 was significantly lower than that in plants collected in 1990.

TABLE 12

Se Concentrations (ppm dry weight) in Plants Collected from Kesterson, 1988 – 1998

Year	<i>n</i>	Geometric Mean ^a	Range	Comments
1988	160	2.3 A	0.20 – 13	Kesterson dewatered and filled in the fall, all samples from Grassland habitat prior to filling
1989	272	3.2 B	0.10 – 38	First sampling post filling of Kesterson
1990	246	5.2 C	0.20 – 46	
1991	254	3.6 B	0.20 – 34	
1992	240	3.2 B	0.20 – 24	
1993	280	3.6 B	0.20 – 50	Heavy March rain
1994	312	3.7 B	0.20 – 70	
1995	286	3.4 B	0.20 – 90	
1998	240	3.8 B	0.20 – 68	Ephemeral pools late into the summer

^a Geometric mean Se concentrations not sharing the same uppercase letter are significantly different (Tukey-Kramer HSD $P \leq 0.05$).

Spatial and Temporal Selenium Concentrations in Plants

Selenium concentrations at Kesterson show a gradient of decreasing concentration in plants and other biota from south to north. The geometric mean selenium concentration in plants collected from Trisection 1 was higher (although not significantly every year) than that in plants from Trisections 2 and 3.

TABLE 13

Summary of Se Concentrations (ppm dry weight) in Collected from Kesterson, 1989 – 1998

Trisection	<i>n</i>	Geometric Mean ^a	Range
1	708	4.4 A	0.20 – 90
2	759	3.3 B	0.20 – 34
3	823	3.1 B	0.10 – 68
Kesterson	2290	3.5	0.10 – 90

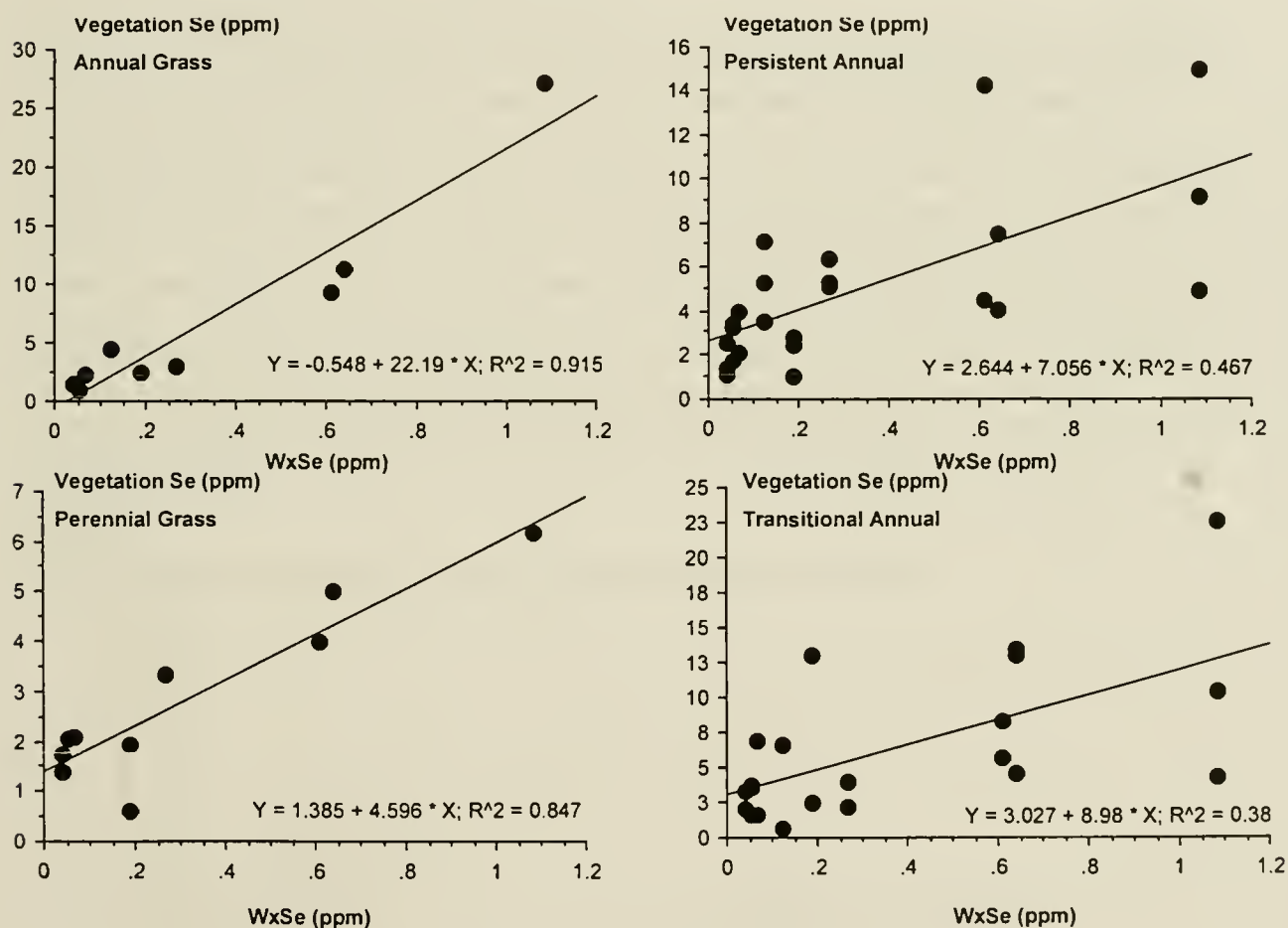
^a Among Trisections, plant Se concentrations not sharing the same uppercase letter are significantly different (Tukey-Kramer HSD $P \leq 0.05$).

Although conditions at Kesterson, and selenium concentrations in much of the biota were different prior to dewatering and filling of Kesterson in 1988, selenium concentrations in plants remained fairly constant. However, there is high variability of selenium concentrations both within and among years. Mean concentrations have remained elevated over background (i.e., > 4 ppm) in many plants without any clear long-term trend toward higher or lower concentrations.

Soil-Plant Selenium Relationships

Selenium concentration in plants is partially controlled by the available selenium in soil. However, in most years the relationship between total soil selenium or water-extractable soil selenium and selenium in plants is confounded by edaphic and other factors. Although there is a general increase in plant selenium as soil selenium increases, this relationship is highly variable (Ohlendorf and Santolo 1994, Santolo 1994). Using the geometric mean selenium concentrations for plants collected at each sample station and the water-extractable soil selenium at that station, there was a good relationship observed for plant groups in 1998 (especially Annual and Perennial Grasses).

FIGURE 9
Relationship of Water-extractable Selenium (WxSe) to Plant Groups, 1998.



Discussion

Overall selenium concentration of plants collected during 1998 (3.8 ppm) was significantly lower than in plants collected in 1990 (5.2 ppm). Since filling of the site in 1988, selenium concentrations in plants have ranged from 2.3 ppm in 1988 (only Grassland habitats sampled) to 5.2 in 1990. Since 1990, concentrations have been more stable, ranging from 3.2 ppm in 1992 to 3.8 ppm in 1998.

Plants collected from Open habitats have higher selenium concentrations than plants from other habitat types, although the levels have varied from year-to-year. Since 1988, Open habitat plants have had higher concentrations of selenium in all years except 1990 and 1994.

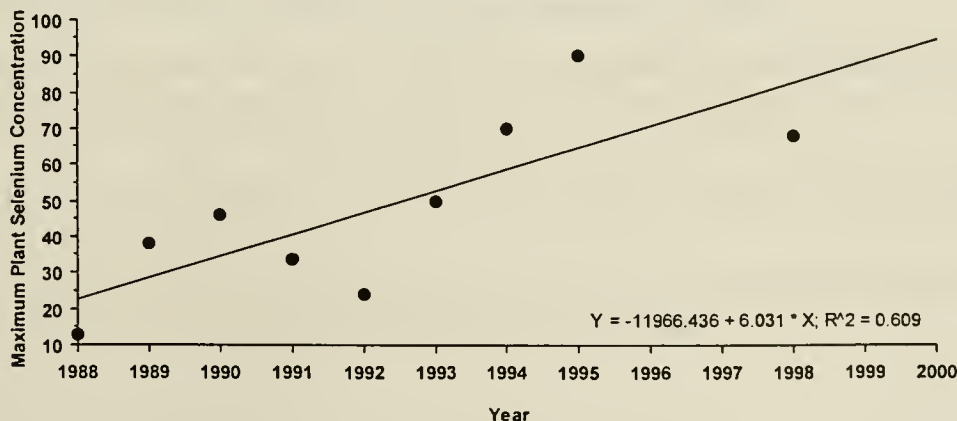
Comparing selenium in plants collected during 1998 showed that plants collected from Trisecton 1 (4.8 ppm) had significantly higher geometric mean selenium concentrations than plants from Trisecton 2 (3.1 ppm).

Selenium is highly variable in plants at Kesterson. Wildlife foraging at Kesterson are more likely to be exposed to plants with high selenium concentrations in Trisecton 1 and Open habitats than in other areas. However, based on the geometric mean selenium concentrations in plants collected from Kesterson, few individuals will be exposed to average plant levels greater than about 4.0 ppm.

Since 1988, selenium in vegetation at Kesterson has fluctuated, but the geometric mean has remained below 3.8 ppm in all but one year (1990 [Table 12]). Although the geometric mean selenium concentrations appear to have stabilized from 1988 to 1998, a significant increase was observed in the maximum plant selenium concentration (from 13 ppm in 1988 to 90 ppm in 1995; $R^2=0.68$). For the first year since 1992, the maximum selenium concentration in plants sampled decreased (to 68 ppm), although it is still higher than any year before 1994 when it was 70 ppm (Figure 10). The maximum selenium concentrations were found in annual grass samples six out of the nine years (including 1998) collected from Trisecton 1, one from Trisecton 2, and one from Trisecton 3 (1998). Four were collected from Grassland and five from Open (including 1998) habitat types. The increasing maximum concentrations and stable relatively low geometric mean concentrations suggest that areas with high bioavailable selenium for plants are becoming localized to small areas of Kesterson and may pose a greater risk to sedentary individuals than to populations foraging on plants site-wide.

FIGURE 10

Maximum Selenium Concentration (ppm, dry weight) in Plants from Kesterson, 1988 – 1998



Site-wide mean plant selenium is below 4.0 ppm and levels vary with plant species, climatic conditions, and location within Kesterson. Since 1990, when overall selenium concentrations in plants reached their highest level (5.2 ppm), mean Se levels have not changed significantly and have averaged below 3.8 ppm or lower. Changes in maximum selenium concentration from year-to-year are possibly due to changes in environmental conditions at the site (i.e., high or low rainfall [drought], temperature fluctuations, soil nutrients, pH, or other edaphic factors), timing of plant growth, or changes in the inventory of selenium available for uptake by plants.

The trend of higher selenium observed in previous years in the vegetation from Trisection 1, where drainwater originally entered Kesterson, was evident in 1998: Plants from Trisection 1 had significantly higher concentrations (4.8 ppm) than those collected in Trisections 2 and 3 (3.1 and 3.6 ppm). Also, the trend of significantly higher selenium concentrations in vegetation collected from Open habitats (7.9 ppm) and lower concentrations in plants from Filled habitats (2.9 ppm) and Grassland habitats (2.5 ppm) was observed again.

Vegetation should not show great variance from the current levels without changes in conditions that would make selenium inventories at the site more available for plant uptake. Timing of rainfall, temperature, and other environmental factors may change conditions from year-to-year resulting in the small fluctuations in selenium observed in plants. 1998 was an unusual weather year and many plants that have been sampled in other years were not available during the sample period. Plants also grew more slowly than they normally would. How this affects selenium availability or plant uptake is unknown.

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5. Selenium in Invertebrates

Introduction

Invertebrates are important as first- (i.e., herbivores and detritivores) and second- (i.e., carnivores) order consumers that are closely associated with plants. They are also important as food items providing an important source of protein for birds and mammals, especially during the breeding season. The effect of elevated selenium to invertebrates, especially terrestrial invertebrates, is not known and has not been well studied (NIWQP 1998).

Population fluctuations of invertebrates at Kesterson are likely due to factors other than selenium, such as climatic changes and plant succession. Studies at Kesterson have been designed to evaluate invertebrates as an exposure route to vertebrate animals (i.e., birds and mammals).

During the 1998 sampling period much of Kesterson was covered by water. Lack of upland habitat and mortality in some species due to flooding (e.g., low grasshopper populations in wet years are attributed to high mortality during the early instar stages due to drowning), retarded plant growth (i.e., reducing the food available to many invertebrates), and possibly high predation rates may have reduced the terrestrial invertebrate population at Kesterson during avian and mammalian the breeding period in 1998. Because of these factors, few terrestrial invertebrates were collected until late in the 1998 sampling season. Also with the retarded plant growth in 1998, more predatory and fewer herbivorous invertebrates were captured during the sample period. Selenium concentrations in carnivorous and scavenger species tend to be higher than concentrations in herbivorous species.

Objectives

The objective of the invertebrate sampling and analysis was to determine the selenium available to wildlife from common invertebrates found at Kesterson.

Methods

Invertebrate Collections

Terrestrial invertebrates were collected for selenium analysis with pitfall traps and by hand. The minimum target weight for each sample for analyses was 0.2g (wet weight). Pitfall traps were used to collect ground-foraging invertebrates. These traps were set up at each sample station in each macrohabitat (i.e., Grassland, Filled, and Open habitats). Moist soil and vegetation were placed at the bottom of each trap and a cover was placed about 1 to 2cm above the trap to protect the samples from the elements and foraging predators. Active searching for invertebrates was also a collection method; each station was searched by turning over rocks, boards, and debris found at the station.

Selenium Analysis

Samples were stored at -20° C, then shipped to a commercial laboratory (Environmental Trace Substances Research Center, Columbia, Missouri) from 1987 to 1991. After 1991, samples were shipped to Laboratory and Environmental Testing (Columbia, Missouri) on dry ice for total selenium analysis.

Results

The geometric mean selenium concentrations in invertebrates collected in 1998 ranged from 1.8 ppm in grasshoppers to 61 ppm in beetles (Table 1). When beetles were separated into herbivores and carnivores (i.e., predatory and carrion-eating beetles), the carnivorous beetles and spiders had significantly higher geometric mean selenium concentrations than was found in herbivorous beetles and grasshoppers. Beetle (lumped together for comparison to other years) selenium concentrations were not significantly different from other invertebrates in 1998.

TABLE 1

Summary of Selenium Concentrations (ppm dry weight) in Invertebrates Collected from Kesterson, 1998

Species	n	Geometric Mean ^a	Range
Aerial insects ^b	1	7.8	
Beetles	64	17 AB	4.2 – 61
Carnivorous Beetles	44	23 A	5.7 – 61
Herbivorous Beetles	20	9.6 B	4.2 – 36
True Bugs	1	11	
Crickets	4	12 AB	3.9 – 24
Grasshoppers	34	7.2 B	1.8 – 17
Spiders	34	17 A	8.1 – 36
All Invertebrates	139	14	1.8 – 61

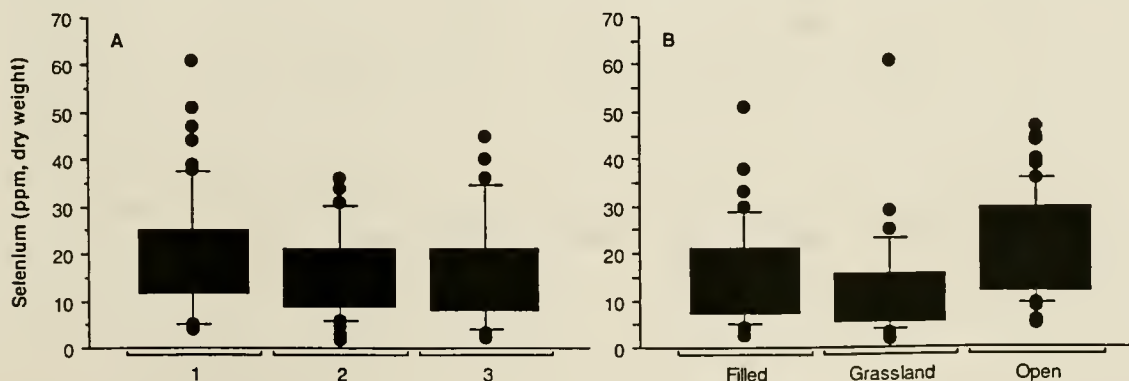
^a There was no significant difference in selenium concentrations among species in 1998 (Tukey-Kramer HSD $P \leq 0.05$).

^b These are mixed aerial insect caught in sweep nets and they were not identified.

Selenium concentrations in invertebrates among the three trisections were not significantly different in 1998 (Figure 1A), but selenium in invertebrates from Open habitat were significantly higher than those from Grassland and Filled habitats (Figure 1B).

FIGURE 1

Box Plots of Selenium Concentrations in Invertebrates Among Trisections (A) and Habitat Types (B). The Bars from the bottom up are the 10th, 25th, 50th, 75th, and 90th percentiles, the circles are outliers.



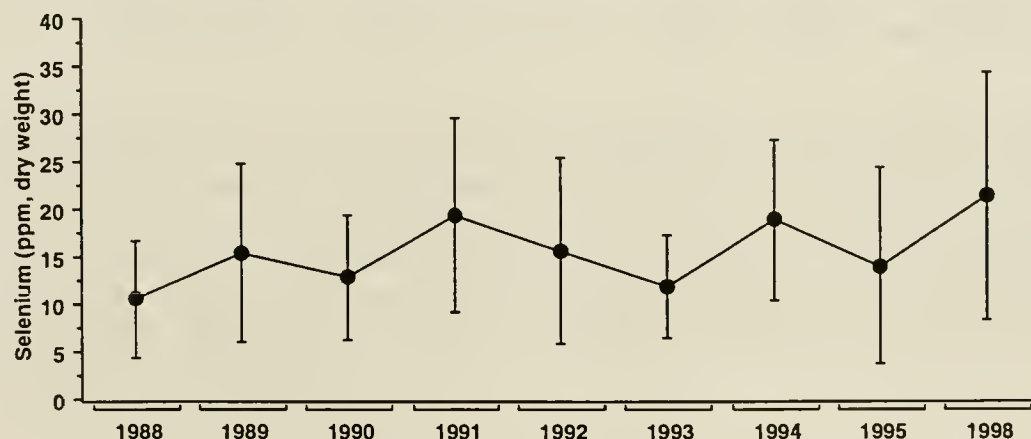
All statistical comparisons were made using geometric means (GM) because selenium concentrations are not normally distributed and show a positive skew of the data. For looking at yearly comparisons, all years were compared to 1998, differences among other years have been reported in previous reports and are not addressed here. Arithmetic means ($\bar{x}$) and standard deviations ($\pm$ SD) were used to show annual trends (except where noted) and they show the same trends as GMs, however, the arithmetic means are generally higher than geometric means.

- **Beetles** are abundant at Kesterson and were found in all habitats and trisections (Table 2). A variety of beetles with different feeding strategies inhabit Kesterson. These include plant-eating beetles (herbivores), meat and invertebrate eaters (predatory beetles; carnivores), and beetles that eat decomposing matter (detritus; detritivores). All beetles were grouped together for comparisons among habitats and years. Selenium was significantly higher in beetles collected from Open habitat than in Grassland habitat. Selenium levels in beetles in 1998 were significantly higher than in beetles from 1988 (GM = 9.1 ppm, n = 40, range = 3.0 – 31; before filling), 1993 (GM = 11 ppm, n = 38, range = 4.0 – 25 ppm), and 1995 (GM = 9.8 ppm, n = 38, range = 0.60 – 40 ppm); Figure 2).

TABLE 2
Selenium Concentrations (ppm dry weight) in Beetles, 1998

Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	n	GM	Range	n	GM	Range	n	GM	Range	n	GM	Range
Grassland	8	18	4.8 – 61	7	9.9	5.7 – 15	1	8.1		16	13	4.8 – 61
Filled	8	18	4.2 – 51	8	12	5.9 – 30				16	16	4.2 – 51
Open	13	20	5.2 – 47	10	19	5.9 – 36	9	27	13 – 45	32	22	5.2 – 47
Kesterson Total	29	19	4.2 – 61	25	14	5.7 – 36	10	24	8.1 – 45	64	17	4.2 – 61

FIGURE 2
Selenium Concentrations in Beetles ($\bar{x}$, $\pm$ 1 SD) Collected at Kesterson, 1988 – 1998.



- Crickets are omnivores whose feeding strategies can include vegetation, detritus, and other invertebrates. Selenium in crickets varied both spatially (by Trisection) and by habitat (Table 2) but only the spatial difference was statistically significant. Cricket selenium levels did not differ significantly among the years samples were collected (Figure 3).

TABLE 3
Selenium Concentrations (ppm dry weight) in Crickets, 1998

Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	<i>n</i>	GM	Range	<i>n</i>	GM	Range	<i>n</i>	GM	Range	<i>n</i>	GM	Range
Grassland				1	13					1	13	
Filled	1	3.9								1	3.9	
Open	1	18		1	24					2	21	18 – 24
Kesterson Total	2	8.4	3.9 – 18	2	18	13 – 24				4	12	3.9 – 24

FIGURE 3
Selenium Concentrations in Crickets ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1988 – 1998.

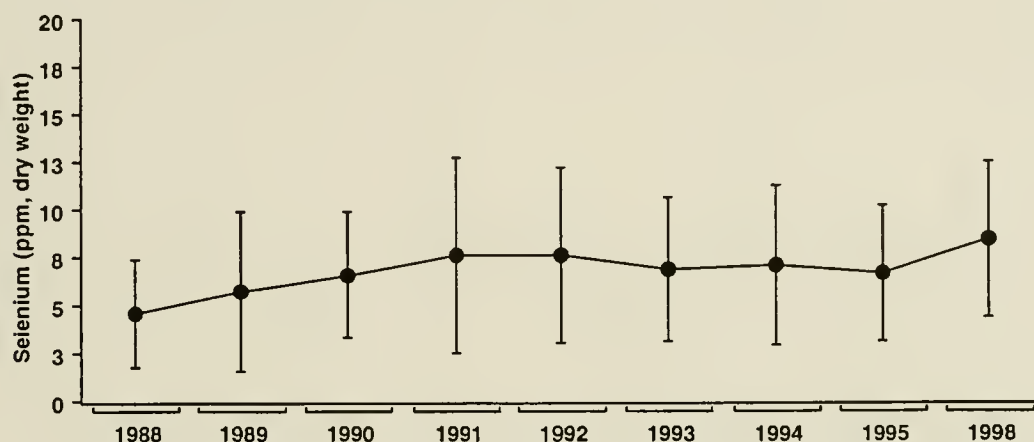


- Grasshoppers belong to the same order as crickets but have a more specialized feeding strategy, foraging only on living plant material. Selenium in grasshoppers varied both spatially (by Trisection) and by habitat (Table 4). Selenium was significantly higher in grasshoppers collected from Trisection 1 than those from Trisection 3 and they were significantly higher in Open than Grassland habitats. Selenium levels in grasshoppers collected in 1998 were significantly higher than in grasshoppers collected in 1988 (prior to filling; GM = 3.9 ppm n = 46, range = 1.0 – 15 ppm) and 1989 (GM = 4.5 ppm, n = 57, range = 0.70 – 25; Figure 4).

TABLE 4
Selenium Concentrations (ppm dry weight) in Grasshoppers, 1998

Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	<i>n</i>	GM	Range	<i>n</i>	GM	Range	<i>n</i>	GM	Range	<i>n</i>	GM	Range
Grassland	5	7.6	5.0 – 14	6	5.6	1.8 – 13	4	3.9	2.1 – 7.3	15	5.7	1.8 – 14
Filled	3	9.9	8.4 – 12	3	6.7	5.9 – 7.4	3	4.3	2.6 – 7.1	9	6.6	2.6 – 12
Open	4	14	11 – 17	3	11	8.8 – 14	3	10	9.6 – 11	10	12	8.8 – 17
Kesterson Total	12	9.9	5.0 – 17	12	6.9	1.8 – 14	10	5.4	2.1 – 11	34	7.3	1.8 – 17

FIGURE 4
Selenium Concentrations in Grasshoppers ($\bar{x}$, ± 1 SD) Collected at Kesterson, 1988 – 1998.

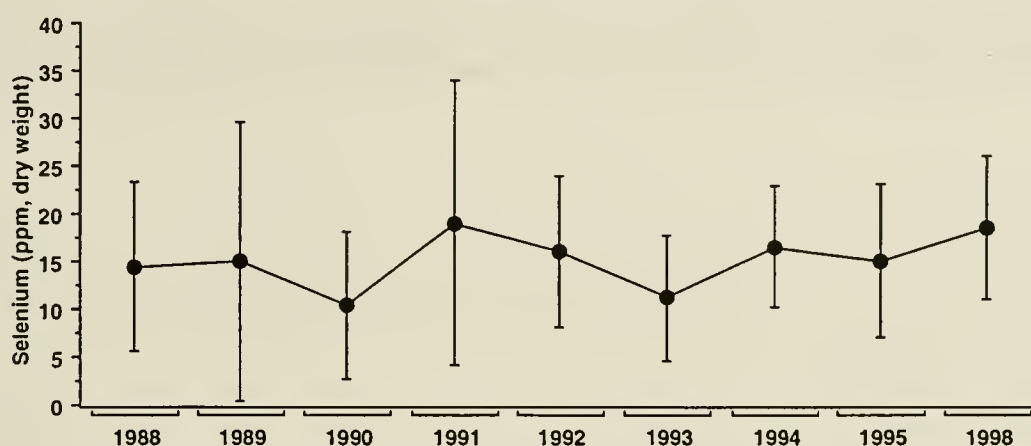


- Spiders are carnivores, feeding exclusively on other invertebrates at the site. They show a wide variation in selenium concentrations, reflecting the range of selenium concentrations in their prey and possibly differences among species. Selenium in spiders varied spatially but not by habitat (Table 5). Selenium was higher in spiders collected from Trisections 1 and 2 than those from Trisection 3. Selenium levels in spiders collected in 1998 were significantly higher than 1989 (GM = 10 ppm, n = 45, range = 2.0 – 84 ppm), 1990 (GM = 8.8 ppm, n = 43, range = 3.6 – 38 ppm), and 1993 (GM = 9.9 ppm, n = 48, range = 3.6 – 45 ppm) spiders (Figure 5).

TABLE 5
Selenium Concentrations (ppm dry weight) in Spiders, 1998

Habitat Type	Trisection 1			Trisection 2			Trisection 3			Kesterson Total		
	<i>n</i>	GM	Range	<i>n</i>	GM	Range	<i>n</i>	GM	Range	<i>n</i>	GM	Range
Grassland	3	19	13 – 25	4	17	12 – 29	1	8.3		8	16	8.3 – 29
Filled	5	21	14 – 33	4	17	11 – 21	4	11	8.1 – 15	13	16	8.1 – 33
Open	4	18	9.1 – 31	5	22	12 – 36	5	16	10 – 22	14	19	9.1 – 36
Kesterson Total	12	20	9.1 – 33	13	19	11 – 36	10	13	8.1 – 22	35	17	8.1 – 36

FIGURE 5
Selenium Concentrations in Spiders ($\bar{x}$, $\pm$ 1 SD) Collected at Kesterson, 1988 – 1998.



Other Invertebrates

A small number of aerial insects were collected using sweep nets and true bugs were collected in small numbers in pitfall traps. Selenium concentrations in both these samples were consistent with other invertebrate levels.

Temporal and Spatial Selenium Concentrations in Invertebrates

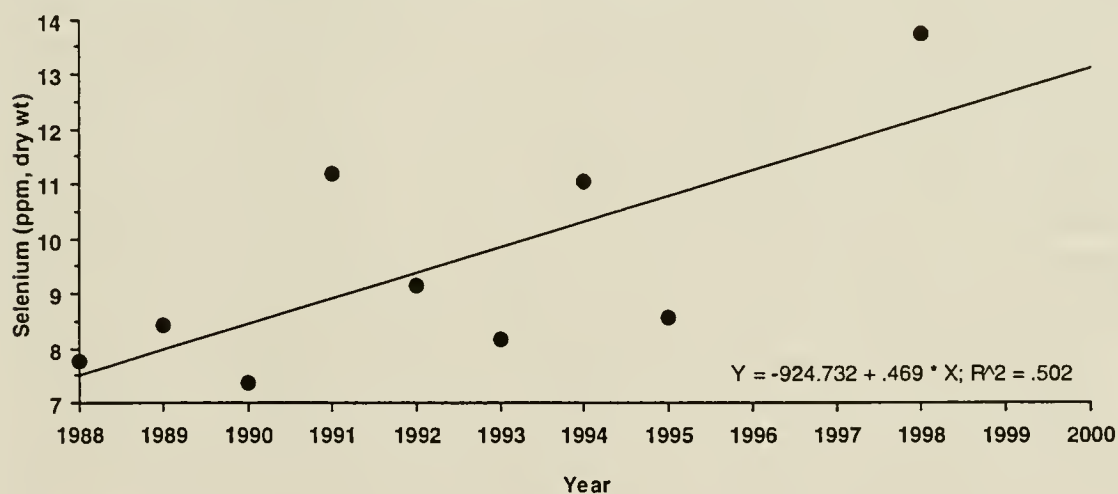
Selenium concentrations in combined invertebrates collected in 1998 were significantly higher than those collected in 1988 – 1990, 1992, 1993, and 1995 (Table 6). Selenium concentrations in invertebrate samples have decreased over short periods (e.g., 1991 – 1993) but generally have shown an increasing long-term trend since 1988 (Figure 6).

TABLE 6
Selenium Concentrations (ppm dry weight) in Invertebrates Collected from Kesterson, 1988 – 1998

Year	n	Geometric Mean ^a	Range	Comments
1988	158	7.8 C	1.0 – 51	Kesterson dewatered and filled in the fall, all samples from Grassland habitat prior to filling
1989	195	8.4 C	0.43 – 84	First sampling post filling of Kesterson
1990	120	7.4 C	0.70 – 38	
1991	143	11 A,B	1.6 – 73	
1992	106	9.2 B,C	1.9 – 43	
1993	153	8.2 C	1.5 – 45	Heavy March rain
1994	173	11 A,B	1.3 – 40	
1995	145	8.6 C	0.60 – 48	
1998	139	14 A	1.8 – 61	Ephemeral pools late into the summer

^a Geometric mean Se concentrations not sharing the same uppercase letter are significantly different (Tukey-Kramer HSD $P \leq 0.05$).

FIGURE 6
Geometric Mean Selenium Concentration in Invertebrates from Kesterson, 1988 – 1998.



Selenium concentrations at Kesterson show a gradient of decreasing concentration in invertebrates and other biota from south to north (Table 7) since Kesterson was filled in 1988. As in plants, the geometric mean selenium concentration in invertebrates collected from Trisection 1 was higher (although not significantly every year) than that in invertebrates from Trisections 2 and 3.

TABLE 7

Summary of Selenium Concentrations (ppm dry weight) in Invertebrates Collected from Kesterson Since Filling, 1989 – 1998

Trisection	<i>n</i>	Geometric Mean ^a	Range
1	400	12 A	1.0 – 84
2	409	9.9 B	1.8 – 45
3	365	7.4 C	0.43 – 73
Kesterson	1174	9.5	0.43 – 84

^a Among Trisections, selenium concentrations not sharing the same uppercase letter are significantly different (Tukey-Kramer HSD $P \leq 0.05$).

Discussion

Although conditions at Kesterson (and selenium concentrations in much of the biota) were different prior to dewatering and filling of Kesterson in 1988, overall mean selenium concentrations in invertebrates have been increasing (Figure 6). The invertebrates were expected to reflect the selenium levels found in their major food items (plants and other invertebrates) at Kesterson. One way to evaluate the movement of selenium through the food chain is by determining a bioaccumulation factor. Example bioaccumulation factors include the ratio of invertebrate selenium to that in plants, or selenium in carnivores to that in herbivores (of course, many carnivorous invertebrates would also eat other carnivores). In 1989 selenium concentrations in invertebrates were about 1.7 times the overall geometric mean in plants. During 1991 and 1992 selenium concentrations in invertebrates were about 3.25 times the plant levels and in 1993 the bioaccumulation factor was about 2.3. In 1995, the bioaccumulation factor from plants to invertebrates was about 2.5. In 1998 samples, the invertebrate bioaccumulation factor from plants (GM 3.8 ppm) to herbivorous terrestrial invertebrates was again about 2.5, the same as that in 1995. The bioaccumulation factor from herbivorous invertebrates to predatory invertebrates in 1998 was 2.4 (23 ppm/9.6 ppm). Bioaccumulation factors from plants to invertebrates have been consistent since 1993 after being slightly lower in 1989 and higher in 1991 and 1992. In 1998, there may have been a greater abundance of predatory and carrion-eating invertebrates represented in the samples possibly because the retarded plant growth provided less of a resource to herbivores than in other years.. This may have contributed to the higher overall selenium concentrations in terrestrial invertebrates in 1998. However, this is assumed to be the dietary selenium concentration available to insectivorous wildlife feeding at Kesterson. There is high variability of selenium concentrations both within and among years and concentrations are above those suggested as typical for background in terrestrial invertebrates (< 1.5; NIWQP 1998). There is little information on effect levels of selenium to terrestrial invertebrates; however, based the geometric mean in invertebrates at Kesterson and on LOAELs for amphipod tissue of 32 ppm (NIWQP 1998), the levels found in invertebrates at Kesterson are probably below an effect level.

Invertebrates are an important dietary item, especially during the breeding season, for many birds that use Kesterson. Effect levels for dietary exposure of birds to selenium have been suggested as follows (NIWQP 1998):

- I. No Effect. Less than 3 ppm selenium
- II. Reproductive Impairment. 3 – 8 ppm selenium
- III. Toxicity Threshold. Greater than 10 ppm selenium

The mean selenium concentration in invertebrates falls above the Toxicity Threshold for dietary exposure to birds and above the Lowest Observed Adverse Effect Level (LOAEL) for reproductive selenosis in rats of 3 ppm dietary exposure (NIWQP 1998). Most birds that feed at Kesterson feed on a variety of food items over various-sized home ranges and are unlikely to be chronically exposed to food items at the higher range of selenium found in samples. Many animals foraging at Kesterson will likely feed both on- and off-site and among the different trisections and habitats, thereby mitigating their intake of food items with high selenium levels.

Nevertheless, due to the importance of invertebrate prey during the reproductive period there is a potential for risk to birds from exposure to selenium in their invertebrate diet. Also, insectivorous birds, especially those with small home ranges, may be at greater risk. A single western kingbird, an insectivorous bird, caught at Kesterson in 1998 had a blood selenium concentration of 64 ppm and western meadowlarks collected in 1998 had a geometric mean selenium concentration of 12 ppm ($n = 8$, range = 7.8 – 18 ppm). Western meadowlarks have been monitored in the past (1988 – 1990) and no reproductive effects were found, although the data set was small. European starlings, another insectivore, have also been studied at Kesterson and although blood selenium ranged from 1.7 to 16 ppm and 30 eggs from 42 nests were examined, no signs of selenosis were detected. To date, no effects of selenium have been found in terrestrial birds at Kesterson. Continued monitoring of birds, eggs, and invertebrates at Kesterson will increase the sample size and provide further details on whether invertebrate selenium levels put these birds and other animals at risk.

References

National Irrigation Water Quality Program (NIWQP). 1998. *Guidelines for Interpretation of the Biological Effects of Selected Constituents in Biota, Water, and Sediment*. USDI, National Irrigation Water Quality Program Information Report no. 3. 198 pp.

6. Ephemeral Pool Monitoring

Extent of Ponding at Kesterson Reservoir During the 1998 Rainy Season

Extensive rainwater pools formed at Kesterson during the winter of 1997 – 1998. During previous monitoring years the pools have usually been limited to small, well-defined areas of Kesterson. In some years (i.e., 1994) the pools were so limited in duration and extent that no significant aquatic invertebrate populations had time to develop. In contrast, the 1997 – 1998 El Niño winter provided high rainfall to the Kesterson area over an extended period of time. As a result, winter rainwater pools were extensive and persistent for much of the winter and into the late spring. The unusual high degree of ponding and persistence of water on Kesterson offered the opportunity to test the spatial variability of potential selenium exposure from the pools and their associated aquatic invertebrate populations (dietary items) to aquatic birds. The pools varied from a few inches to two – three feet in depth and temporarily covered large areas of the terrestrial habitats of Kesterson.

The pools formed at Kesterson during January and persisted through June of 1998. The areal extent of ephemeral pools was estimated by ground surveys on March 1 and May 1 and by aerial photographs taken February 24 and April 17, 1998. Aerial photographs were digitized and pool areas summed by Pond by USBR staff (USBR 1998a). The approximate maximum extent of ponding during March 1998 at Kesterson is seen in Figure 1. The pools persisted for several months throughout the spring of 1998. The gradually depleting acreage of flooding is shown in Figure 2.

Selenium Monitoring in Ephemeral Pools

Methods

Water and invertebrates were collected from the ephemeral pools on six different dates in the winter and spring of 1998. Water samples were collected as surface, grab samples and analyzed for total selenium concentration from 11 of the 12 Kesterson Ponds. Aquatic invertebrates were collected from the water column or surface sediment of the pools using kicknets and soil sieves, sorted by species, and frozen prior to analysis of total tissue selenium. Biota and water samples were collected at least once during the 1998 season from pools in every Pond except Pond 8. The pools sampled during 1998 are shown in Figure 3.

Results

Water samples ranged from 1 to 61.7 ppb total selenium with a geometric mean of 5.6 ppb selenium. Aquatic invertebrates collected from the same pools ranged from 2.3 to 94 ppm whole body selenium (dry weight basis) with a mean of 20.7 ppm selenium. Summaries by pool for water and invertebrates are shown in Table 1. Patterns of selenium concentration over time in water and invertebrates is shown in Figure 4, a-g. Selenium contamination in

the pools followed a pattern established in previous years at Kesterson. The highest selenium levels were found in water and invertebrates from Ponds 2, 4, 5, and 10 while lower levels were consistently found from the pools of Ponds 6, 7, 9, and 11. Mean selenium concentrations in water boatmen, midge larvae, and micro-crustaceans (*Daphnia* and ostracods) were similar to values from 1997 and previous years. As seen in previous years (USBR 1998b), the highest invertebrate concentrations were found in *Daphnia* populations, particularly from Pond 2. The geometric mean selenium concentration in crustaceans was 31.6 ppm selenium (dry wt.) as compared to the aquatic insect mean concentration of 18.6 ppm selenium. Midge larvae showed the highest concentrations of selenium for insects. The invertebrate means are approximately 3 – 4 ppm lower than those found in 1997 for all groups. The slight drop in bioaccumulation estimates for 1998 may be due to the greatly enhanced sample coverage (121 invertebrate samples versus 22 in 1997) and/or dilution of the water-borne selenium concentrations by the larger pool sizes in 1998.

TABLE 1

Geometric Mean Selenium Concentrations in Water and Invertebrates from Kesterson Reservoir Rainwater Pools, 1998.

Pool Number (Pond, pool)	Mean Water Concentration (ug/L total selenium)	Water Min/Max (n)	Mean Invertebrate Tissue Concentration (mg/kg DW selenium)	Invertebrate Min/Max (n)
1.1	3.3	1.5/6.5 (6)	21.8	8.4/55.0 (18)
1.2	4.0	2.1/5.0 (2)	50.8	29.0/89.0 (2)
2.1	22.6	17.5/33.9 (6)	48.4	30.0/77.0 (6)
2.2	42.6	7.5/61.7 (5)	41.6	10.0/94.0 (9)
3.1	6.2	5.0/10.8 (6)	15.7	10.0/23.0 (7)
4.1	5.0	1.8/13.7 (4)	29.3	11.0/71.0 (11)
5.2	7.8	1.5/9.8 (6)	28.8	15.0/65.0 (15)
6.1	4.6	1.8/8.3 (6)	14.9	5.4/28.0 (8)
7.1	3.2	5.0/5.6 (2)	16.5	12.0/23.0 (4)
9.1	2.0	1.5/5.0 (5)	15.0	6.7/30.0 (14)
9.2	4.6	(1)	32.0	(1)
10.1	4.5	1.8/14.4 (6)	29.2	11.0/86.0 (13)
11.1	1.5	1.0/5.0 (5)	5.3	1.0/20.0 (12)
12.1	2.9	(1)	4.3	(1)

FIGURE 4

Invertebrate Tissue Selenium and Water Concentrations, Kesterson Ephemeral Pools, 1998.

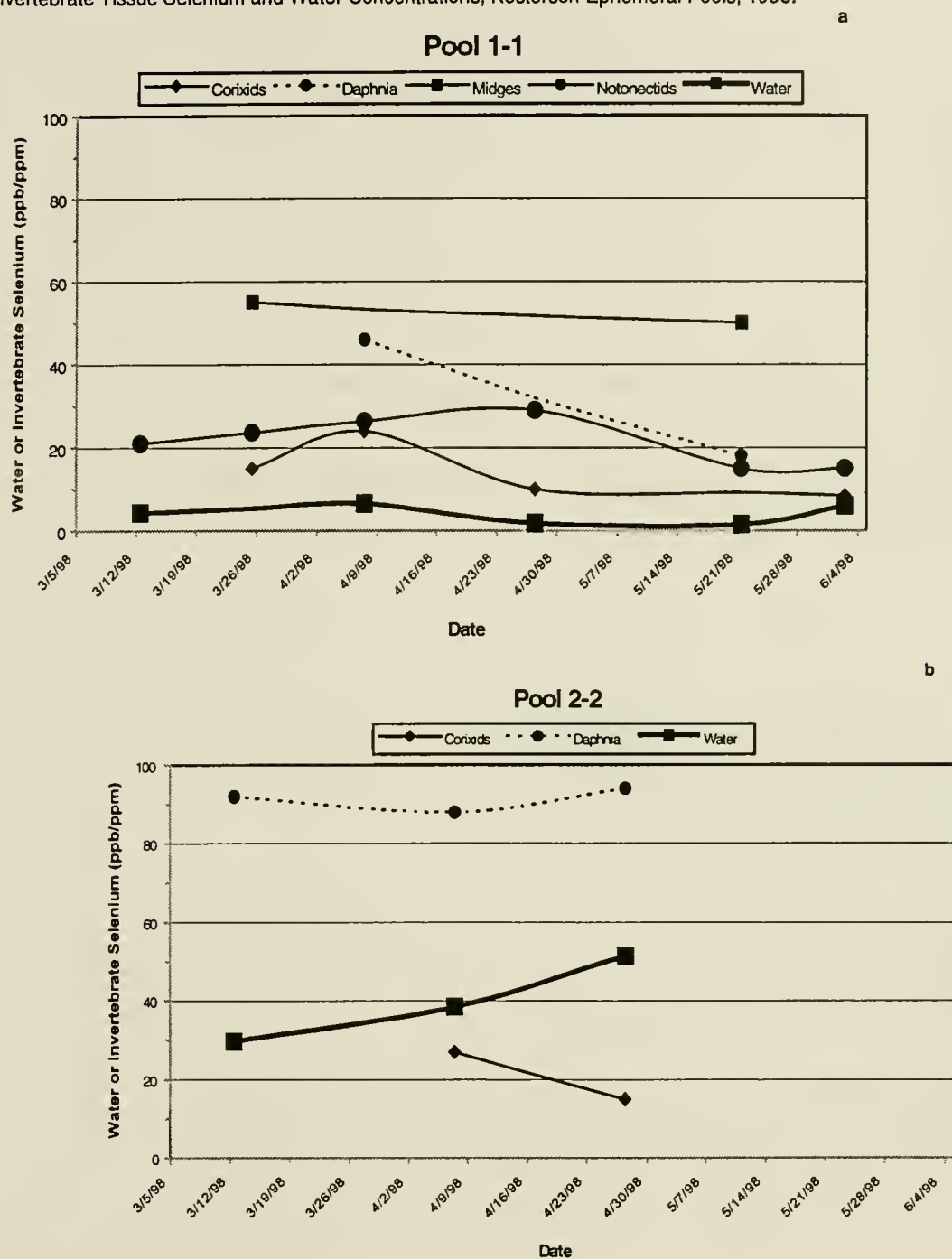


FIGURE 4 (CONT)

Invertebrate Tissue Selenium and Water Concentrations, Kesterson Ephemeral Pools, 1998.

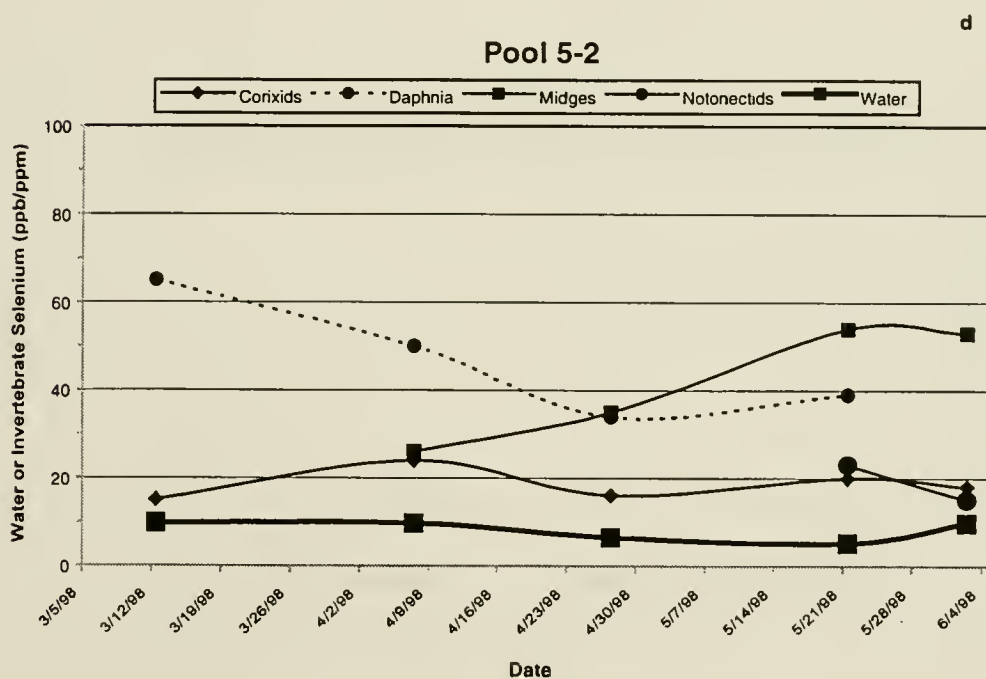
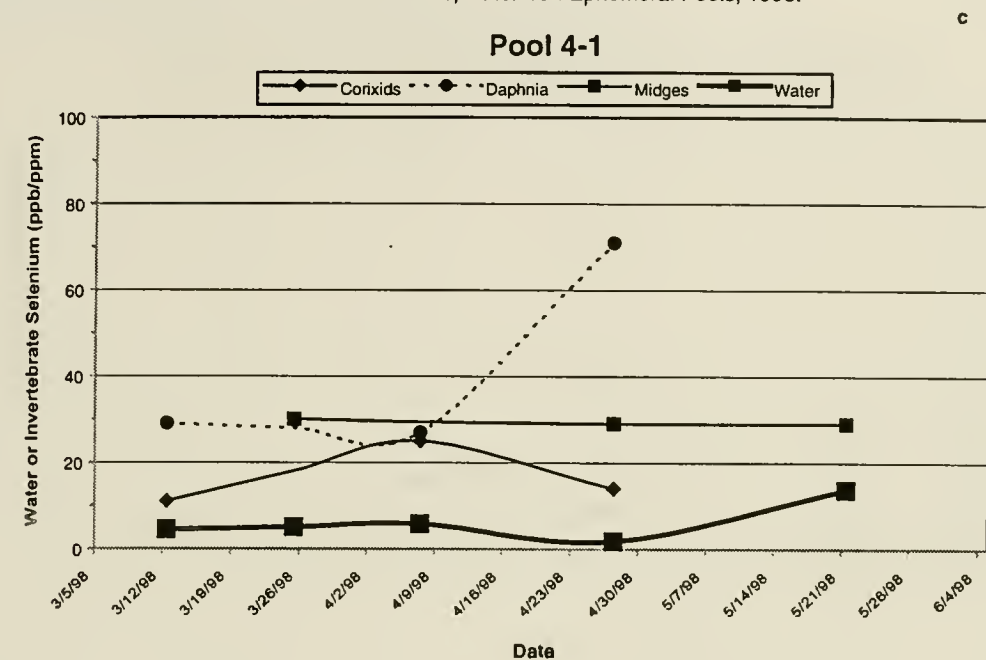
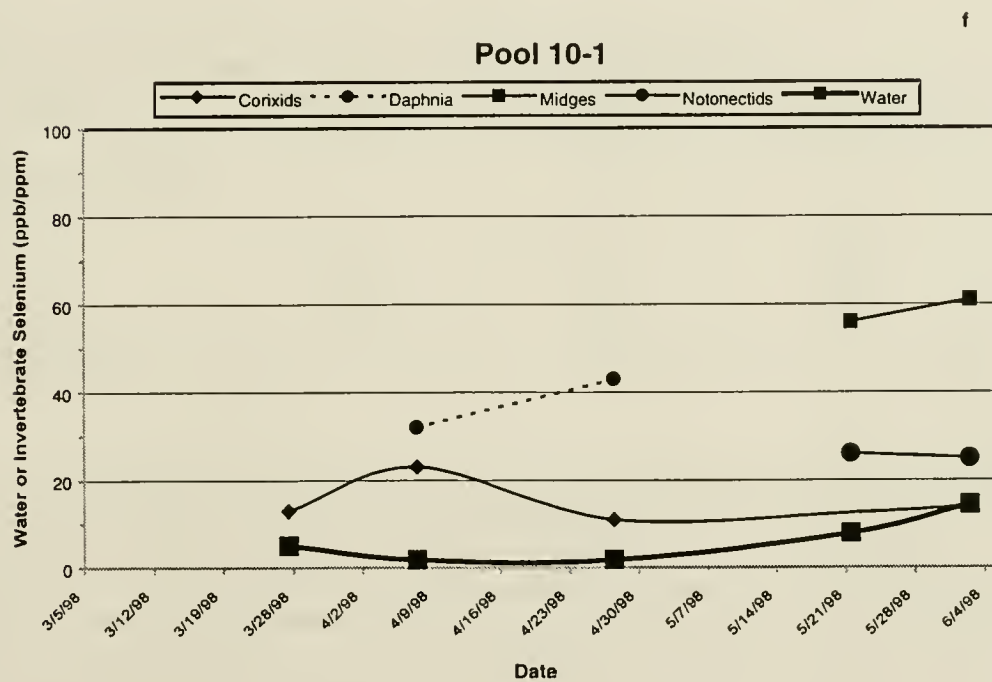
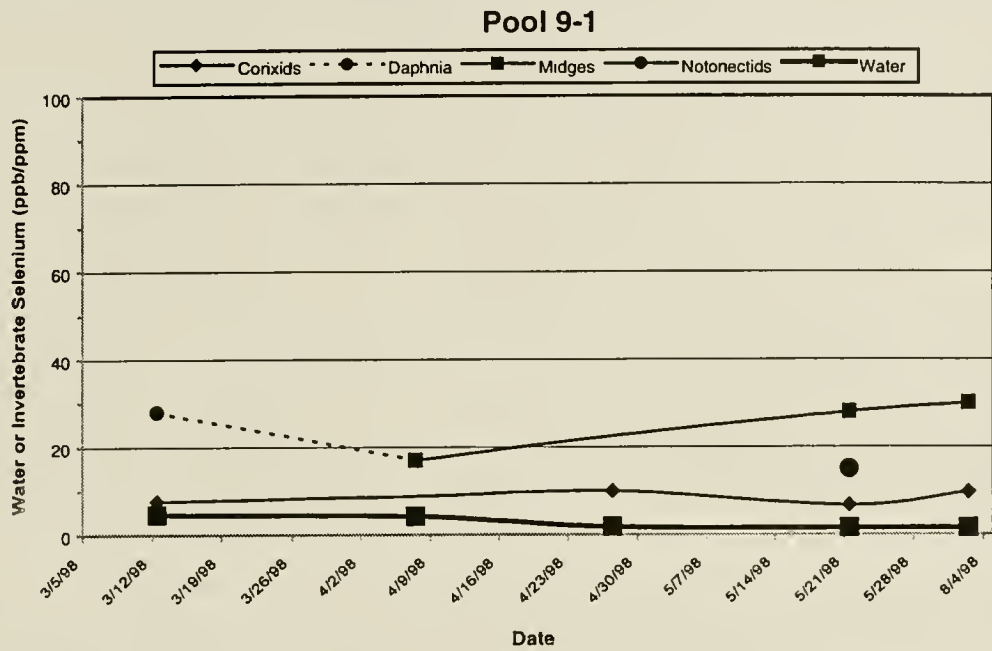


FIGURE 4 (CON'T)

Invertebrate Tissue Selenium and Water Concentrations, Kesterson Ephemeral Pools, 1998.



Note that pools in Ponds 1, 2, 4 and 5 have the highest concentrations of selenium in water and invertebrates while Ponds 9, 10, and 11 show relatively lower concentrations (Figure 4, a – g). The general conclusions supported by Figure 3 and Table 1 is that higher ephemeral pool selenium concentrations are clustered in the southern end of Kesterson (Trisection 1).

The pattern of selenium concentrations in invertebrates over time does not reveal a short-term response to changing waterborne selenium concentrations (Figure 4, a – g). Instead, the most striking differences in invertebrate and water concentrations are among pools. Pools with higher sustained selenium water concentrations tend to have higher selenium concentrations in aquatic invertebrates. This general relationship can be seen in the significant, but highly variable, positive relationship between invertebrate tissue concentrations and water concentrations in the 1998 data set (Figure 5). It is possible that changing water concentrations and lags in bioaccumulation help to explain some of the variability evident in Figure 4. However, no obvious lags in bioaccumulation are evident from the relationships between invertebrate and water selenium shown in Figure 4. It is also possible that more complex aspects of pool chemistry and the balance between waterborne and dietary uptake of selenium in the invertebrates changes among pools and consequently influences the overall degree of bioaccumulation.

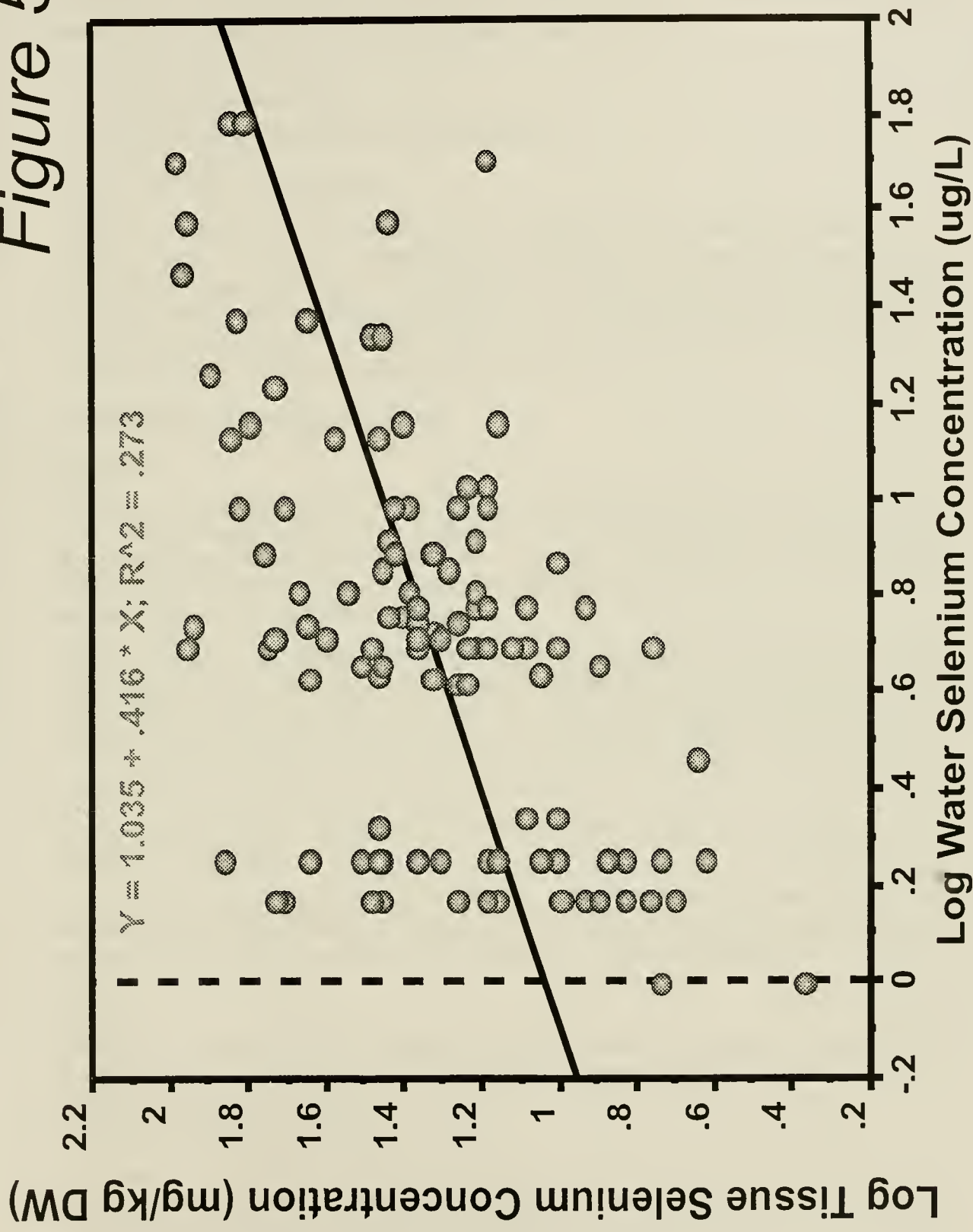
Bioaccumulation factors (invertebrate concentration divided by water concentration) (BAFs) are presented in Table 2. Although maximum BAFs are similar among invertebrate groups, the crustaceans tended to have higher average BAFs at Kesterson pools in 1998 as they have in previous years. Algae BAFs are much reduced over that of invertebrates.

TABLE 2
Bioaccumulation Factors for Selenium in Kesterson Reservoir Aquatic Biota Groups, 1998.

Statistic	Crustaceans	Aquatic Insects	Filamentous algae
Mean BAF (Tissue Se conc. ppb/Water conc. ppb)	7,475	5,867	616
Maximum BAF	39,444	35,333	1,032
Minimum BAF	1,825	291	200
Number of samples	31	87	2

There does not appear to be any clear trends of invertebrate tissue selenium concentrations from the Kesterson pools over time. Mean concentrations of the most consistently sampled taxa are shown for the years of pond monitoring in Table 3. As discussed above, concentrations in 1998 were, on the average, slightly lower than 1997. The relatively high 1997 midge average may have been due to the small number of samples collected that year. Although averages were lower, maximum concentrations observed in 1998 were still representative of highly contaminated conditions with maximum insect (beetle) and *Daphnia* concentrations of 89 and 94 ppm, respectively (See maximum values, Table 1). Kesterson-wide averages are highly dependent upon the pools where they are collected and the number of samples averaged.

Figure 5





The species selected for analysis were representative of shorebird and/or waterfowl dietary items and groups sampled in previous years and were dominated by:

- midge larvae
- water boatmen (corixidae)
- crustacean zooplankters (*Daphnia* and ostracods)
- ditiscid beetles
- backswimmers (notonectidae)

However, the persistence of the pools in 1998 contributed to an apparent expansion of species diversity. Many more beetle and *notonectid* species were observed and sampled in 1998 than have been typically seen at Kesterson. In addition, adult and juvenile *belastomatids* (giant toe biters) were seen and sampled for the first time. Species shifts were observed within the pools; there was a general trend towards greater density of predators (*notonectids*, *belastomatids*, large beetles) towards the end of the season.

Relative Index of Exposure to Birds

Methods

The acreage of ephemeral pools within each of the Kesterson Ponds was estimated by planimetry of aerial photographs or field-surveyed pond dimensions as depicted on maps. The acreage of pools by pond was measured on February 24, March 1, April 17, and May 1, 1998. The acreage on the dates of water and invertebrate sampling was extrapolated between data on adjacent dates (Figure 2).

Daily bird counts at each of the 12 main Kesterson Ponds were estimated by visual surveys taken during a 2 hour, morning period. Aquatic birds were grouped as shorebirds and waterfowl, as appropriate. Dominant shorebird species were black-necked stilt and American avocet. Dominant waterfowl species were American coot and northern pintail.

The relative exposure index was calculated by Pond as:

Relative Exposure Index = Shorebird or Waterfowl count × pool area × invertebrate selenium concentration

Water and invertebrate concentrations were significantly correlated and, therefore, invertebrate tissue concentrations were assumed to account for the variability in exposure both from water directly and from dietary items living in the different Ponds.

Results

The Relative Exposure Index demonstrates marked variability in selenium exposure risk to aquatic birds with location at Kesterson. In addition, the risk varied greatly with time, strongly influenced by bird use and the declining availability of the ponds as they evaporated in the spring (Figure 2).

The analysis revealed that, although mean selenium concentrations in dietary items and water were relatively elevated in Pond 2 (for example), bird use was relatively low in that area and the exposure index was minimal. Instead, higher relative exposure was found in areas of lower dietary concentration but greater bird use, such as the large, open areas of

Ponds 9 and 11. Index results for the combined Kesterson pool areas and dietary exposure for all Ponds shows a pattern of generally decreasing selenium exposure to water birds over the spring of 1998 (Figure 6). The large differences in index values between waterfowl and shorebirds in early spring was due to the relatively higher numbers of waterfowl frequenting Ponds with relatively higher dietary selenium concentrations. The sharp decline in waterfowl index numbers over time reflects the seasonal movement of waterfowl from the area. In contrast, shorebird abundance at Kesterson was more constant than for waterfowl during the spring and their index values indicate less seasonal change in potential exposure over the period of ephemeral pools in 1998 (Figure 6).

The Relative Exposure Index for selenium exposure to aquatic birds at Kesterson provides a convenient way of examining the spatial distribution of exposure to potentially toxic levels of selenium. Although the general technique could be applied to other environments, the Index as presently developed is specific to exposure at Kesterson. Other aspects of Ecological Risk Assessment are necessary to derive more precise measures of exposure. For example, more precise measures of exposure would take into account the bird's home range and relative feeding in different areas on and off Kesterson as well as an assessment of sediment and water ingestion and dietary fractions for various invertebrate prey items. In addition, selenium toxicity thresholds are not accounted for in the Index. High bird use and relatively nontoxic selenium levels (e.g., 100 birds $\times$ diet of 2 mg/kg) could score as high as lower use with known toxic levels (8 birds $\times$ 25 mg/kg diet). Results must be interpreted in relation to established toxicity information.

The value in the Relative Exposure Index lies in its ability to show spatial areas of exposure that would not otherwise be apparent from an examination of bird use or dietary risk examined separately. For example, although water and invertebrate selenium concentrations were consistently highest in Pond 2, the pools in that area were relatively unused by birds, probably due to a lack of shorebird wading habitat and vegetation in deeper water that precluded swimming habitat for waterfowl. In contrast, areas with high bird use but lower selenium concentrations (Ponds 9 and 11) appeared to have much higher exposure index values. The Index offers a guide to habitat management rather than a true measure of contaminant exposure.

Discussion

The extensive ponding at Kesterson during 1997 – 1998 offered a unique opportunity to examine the maximum potential for ephemeral pool development, the pattern of water and invertebrate selenium concentrations in those pools, and the potential exposure to birds in different areas of Kesterson. It is apparent that areas of Trisection 1, in Ponds 2 and 5 have the greatest potential for the formation of ephemeral pools with elevated concentrations of selenium in water and dietary items. The Relative Exposure Index revealed that restrictions on bird use in Pond 2 act to mitigate exposure. Any such structural characteristics of temporary pools that discourage wading or swimming bird use (such as the dense brush in the wetted areas of Pond 2) effectively limit avian exposure.

The selenium concentrations of water and invertebrates in the ephemeral pools in 1998 exceeded toxicity thresholds for adverse hatchability and teratogenic effects for birds potentially feeding on those items (Skorupa and Ohlendorf 1991). In comparison, the

Kesterson pools exceeded background invertebrate values for comparable taxa at San Joaquin Valley reference sites (NIWQP 1998). Waterborne concentrations observed in 1998 also exceeded the potential toxicity thresholds for foodchain bioaccumulation and exposure to birds. (Exposure would be mainly through feeding on the resident invertebrates of the pools.) All except one invertebrate sample collected in 1998 had selenium at levels above the threshold for potential adverse effects on reproductive success (i.e., > 6.0 ppm dry wt., Heinz 1996). Earlier sampling by USBR staff (USBR 1998b) revealed a pattern of initial high concentrations of selenium in some pools immediately after filling (higher than reported here) followed by later season reductions in concentration that overlap in timing and magnitude with our observations.

The extensive "re-wetting" of Kesterson with ephemeral pools in 1998 provided the opportunity to map areas of potential selenium exposure and to demonstrate that exposure to waterbirds in normal water years is extremely limited in time and space and that exposure can be limited through vegetation management.

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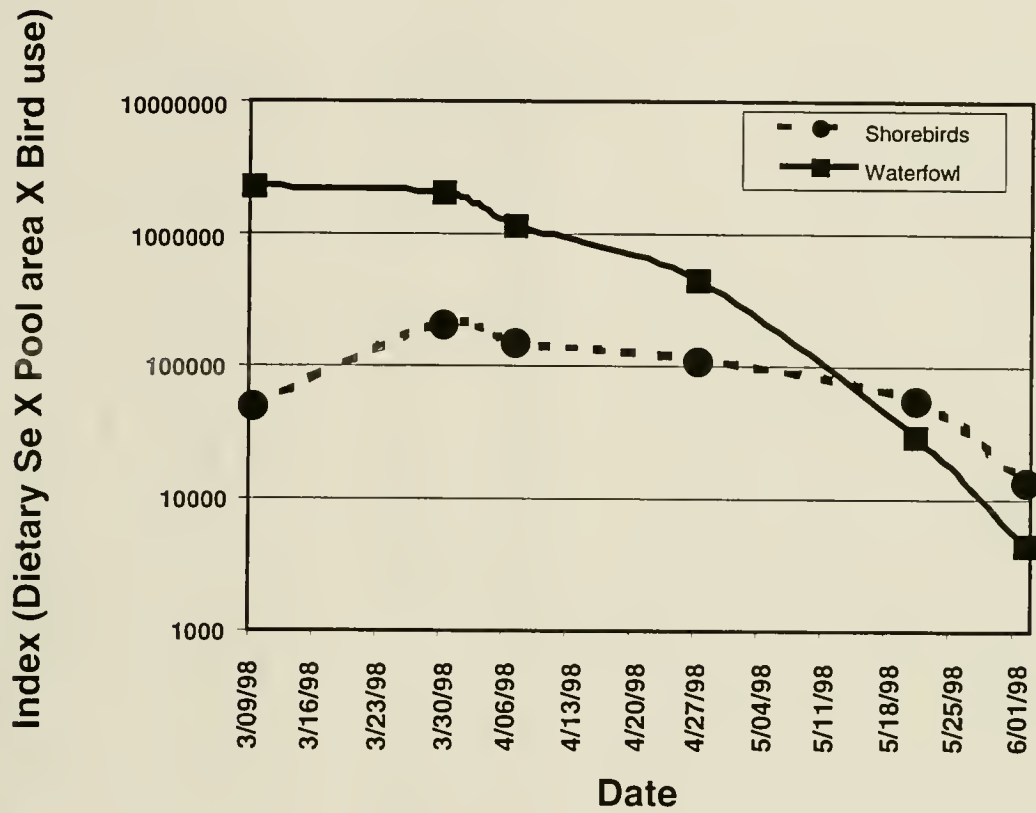


Figure 6. Dietary Selenium Exposure Index

Kesterson, 1998

TABLE 3

Average Tissue Se Concentrations in Aquatic Invertebrates from Kesterson, 1983 - 1998

		Geometric Mean Concentration (ppm) (n)										
		1983	1983	1984	1987	1988	1992 ¹	1993 ¹	1995 ¹	1996 ¹	1997 ¹	1998 ¹
Aquatic Insects												
Corixids	20(1)	16-295 ²		19(3) ³	12.7(13)	10.2(55)	10.7(4)	6.8(9)	13.3(3)	17.3(4)	15.1(4)	12.6(33)
Midge Larvae	200(1)	(insects)		102(3) ²	89.3(24)	39.4(33)	6.7(2)	9.1(2)	14(1)	-	54.1(2)	24.2(23)
Crustaceans												
Daphnia sp.	-	58-120 ²		-	31(1)	-	18.1(4)	15.2(8)	28(1)	57.1(2)	35.4(12)	31.5(28)
Ostracods	-	Net plankton		-	31(1)	-	36(1)	-	-	60(1)	mixed crustaceans	mixed crustaceans

¹Ephemeral pool samples; those prior to 1992 were from Kesterson Reservoir prior to dewatering and the adding of fill soil in 1988.²from Saiki (1985)³from Schuler (1987)

7. Bird Nesting and Reproduction

Introduction

Reproductive effects of selenium have been observed in wild aquatic birds at Kesterson in the past. Effects have included embryo mortality and teratogenesis, along with failure of adult birds to breed (Ohlendorf et al. 1990, Skorupa and Ohlendorf 1991). Monitoring of nests since 1988 has shown continued elevated selenium concentrations in eggs but no evidence of selenium-caused reproductive effects. Nest boxes were set up at Kesterson in 1995 and since then data on European starlings (*Sturnus vulgaris*), American kestrels (*Falco sparverius*), and barn owls (*Tyto alba*) have been collected. Egg selenium concentrations and success of birds nesting in the boxes is included here for comparison to other birds nesting at Kesterson. However, the results of the nest box studies are discussed in greater detail in the Nest Box and Telemetry Study.

In 1998, rainfall was heavier than normal, especially during the breeding period for many of the bird species that utilize Kesterson. Plant, invertebrate, and small mammal sampling indicated that the reproductive season for many species was delayed or interrupted. With the delayed growing season for many plant species, the animals that depend on these plants were unable to use them as forage or for shelter. This may have disrupted nesting for some terrestrial species including raptors that depend on small mammal populations and insectivorous birds and mammals that depend on terrestrial invertebrates to feed themselves and their growing young. However, with heavy rain continuing so late in the year, rainwater pools persisted throughout Kesterson and some shorebirds (i.e., black-necked stilts [*Himantopus mexicanus*] and American avocets [*Recurvirostra americana*]) that are not normally observed nesting at Kesterson nested in relatively high numbers (i.e., stilts), possibly because aquatic invertebrates were abundant in these pools.

Objectives

The objectives of this study were to determine selenium concentrations in bird eggs and to assess the reproductive success of birds at Kesterson. Reproductive success was evaluated by determining the frequencies of embryonic mortality and developmental abnormalities, as well as hatching success of birds nesting during spring and summer of 1998.

Methods

Nest Searches

From mid-February through June 1998, biologists searched for and monitored, on a weekly basis, nests of shorebirds, waterfowl, and terrestrial species at Kesterson. Most killdeer (*Charadrius vociferus*) nests were located by driving slowly along the levee roads and watching for the adult leaving the nest, displaying, or "sneaking" away from the nest. Other bird nests were located by looking for birds displaying behaviors associated with nesting

activities, searching for adults on nests with binoculars, and opportunistically finding nests while conducting surveys and other activities.

Nest Monitoring

After a nest was found, it was marked with flagging approximately 10ft away from the nest, the location was identified on a data sheet, and the nest was given a unique code. Nest codes include four-letter species acronyms, the pond number, and a nest number. Monitoring of the nest began immediately after its discovery and continued on a weekly basis to assess hatching success and nestling survival. Monitoring was conducted with minimum disturbance to the nesting birds. Each time the nest was visited the date, nest code, and number and condition of eggs were recorded on data sheets. A nest was considered unsuccessful if all eggs failed to hatch. Nests were considered abandoned if a clutch was not completed or the nest appeared unattended on subsequent visits and eggs were cold. Predation of the nest was determined by disappearance of eggs from a nest before the expected hatching date or observation of partially eaten eggs or egg contents in the nest (Mayfield 1975, Ohlendorf et al. 1989).

Egg Collections

After a stilt, avocet, killdeer, or duck nest was located, one egg was removed immediately if the nest contained two or more eggs and (in 1998) two eggs were removed if the nest contained three or more eggs. Eggs were not collected from some nests for various reasons such as that some nests were found and the egg(s) lost to predators before they could be collected or too few eggs were in the nest for collection (these nests appear in Table 1). All eggs were collected from starling nests. One egg was removed from other nests (except as noted above). At collection, each egg was marked with its unique nest code and the date it was removed. The data were recorded on a data sheet and the egg was placed in a container to avoid damage. One of the two stilt, avocet, killdeer, or duck eggs (referred to as "incubation eggs") and some of the starling eggs were transported to UC Davis where the egg was placed in an incubator. All other eggs (hereafter, "monitor eggs") removed from nests were either examined or refrigerated within 1 hour of collection.

Embryo Ages

Eggs were usually collected as soon as a nest was discovered to avoid losing samples to predation and to maximize the number of nests sampled for selenium. Embryos were considered viable if the egg was fertile or a living embryo could be observed (i.e., during breakout or candling). Most eggs contained embryos under 10 days old, before most abnormalities that are characteristic of selenium toxicity can be observed and were classified as being normal and viable. However, embryo mortality is not distributed randomly during incubation of the egg. There are generally two embryo mortality peaks, one at about 2 to 3 days of development and a second, more pronounced mortality peak between 18 and 20 days of development. These peaks coincide with fundamental changes in physiological functioning of various parts and organs (Landauer 1967). Because most eggs were collected early during incubation, viability is likely over-represented (i.e., many eggs had early embryos that might have died in the later "mortality peak") for these samples.

To better determine the incidence of embryo abnormalities due to selenium, a single egg from most stilt, avocet, and killdeer nests was artificially incubated until the embryo reached the later stages of development. Overall, preliminary results of this study support the findings of the monitoring observations that selenium-caused embryonic mortality is not occurring in most embryos at Kesterson (Steven Detwiler, University of California, Davis, personal communication). The details of the incubation study and the complete results will be presented in a supplement to this report.

Also, a preliminary analysis of the probability of selenium-induced embryo teratogenesis and egg viability in stilts and killdeer was conducted using response curves for these species (Joseph Skorupa, USFWS, personal communication). Eggs ≥ 7 days into incubation were compared to the response curve for selenium-induced teratogenesis and a logistic regression equation for clutch-wise probability of ≥ 1 inviable egg was fitted.

Laboratory Examinations

Each of the monitor eggs was opened as soon as possible after collection to determine its fertility, stage of development, the position of the embryo, and whether pipping had occurred (i.e., whether the embryo had begun to break out of the egg). Each embryo was examined for evidence of external deformities. The entire egg contents were then saved in chemically cleaned containers and frozen until shipment to the laboratory for selenium analysis.

Results

The results of nest monitoring and egg collections from 1998 are presented in Table 1. Eggs that were not collected randomly (i.e., an unhatched egg from a clutch) are noted. These nonrandom eggs were not used in analyses of selenium trends but are presented in Table 1 to provide information and to determine whether failure to hatch may have been due to elevated selenium levels in the egg.

TABLE 1
Results of Nest Observations and Se Analysis of Eggs, Kesterson 1998

Species	Location	Date	Embryo ^a		# Eggs	Egg-Se	
		Collected	Day ^b	Stage	Clutch	DW	Fate of Nest
American avocet	P03-01	20-May	2	8	4	7.9	Abandoned
American avocet	P03-02	3-Jun	3	16	4	2.5	Predation
American avocet	P11-01	15-May	0		2	3.2	Predation
American avocet	P12-01	19-Apr	0		3	2.9	Predation
American kestrel	NB01-02	5-Apr	4	13	5	3.1	Predation
American kestrel	NB01-04	5-Apr	3	8	6	2.3	Successful-4 eggs hatched
American kestrel	NB01-04	9-May	R	R	6	2.9	Unhatched egg, nest unsuccessful
American kestrel	NB02-02	28-Jun	3	8	2	3.8	Abandoned
American kestrel	NB04-05	5-Apr	1	3	4	4.8	Successful-3 eggs hatch

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Results of Nest Observations and Se Analysis of Eggs, Kesterson 1998

Species	Location	Date	Embryo ^a		# Eggs	Egg-Se	Fate of Nest
		Collected	Day ^b	Stage	Clutch	DW	
American kestrel	NB04-05	9-May	R	R	5	5.0	Unhatched egg, nest successful
American kestrel	NB12-02	19-Apr	16	36	5	5.0	Successful-3 eggs hatch
American kestrel	NB12-04	24-Jun	22	41	5	2.3	Successful-4 eggs hatched
American kestrel	NB140-01	19-Apr	3	8	5	2.2	Unsuccessful
American kestrel	NB165-01	5-Apr	20	39	6	3.5	Successful-5 eggs hatch
Barn swallow	P02-01	22-May	0		2	7.0	Successful
Barn swallow	P02-02	20-Jun	0		3	6.9	Successful
Barn swallow	P04-01	28-Jun	6		3	6.0	Successful
Barn owl	BO 04-02a	12-May	-	-	7	2.8	Abandoned
Barn owl	BO 04-02b	12-May	13	-	7	4.2	Abandoned
Barn owl	BO 03-01	18-Apr	3	8	6	2.4	Successful
Barn owl	BO 04-01	27-Mar	R	R	4	6.7	Predation
Barn owl	BO 05-01	27-Mar	1	3	4	2.8	Successful-4 eggs hatch
Barn owl	BO 05-01	12-Dec	0	2	2	3.1	Abandoned
Barn owl	BO 03-01	15-Nov			5	No egg	Successful-4 eggs hatch
Black-necked stilt	P01-01	9-Apr	1	8	4	11	Predation
Black-necked stilt	P01-02	15-Apr	7.5	33	3	5.3	Predation
Black-necked stilt	P01-03	15-Apr	2	8	4	8.4	Predation
Black-necked stilt	P01-04	18-Apr	0		4	5.4	Predation
Black-necked stilt	P01-05	19-Apr	7	30	4	8.8	Predation
Black-necked stilt	P02-01	26-Apr	6	29	4	42	Predation
Black-necked stilt	P03-01	15-Apr	0		2	23	Abandoned
Black-necked stilt	P03-02	19-Apr	3	18	4	17	Predation
Black-necked stilt	P03-03	29-Apr	4	23	4	20	Successful
Black-necked stilt	P03-04	16-May	5		4	8.6	Successful
Black-necked stilt	P04-01	26-Apr	8	33	4	20	Predation
Black-necked stilt	P04-02	19-Apr	5	26	4	19	Predation
Black-necked stilt	P04-03	26-Apr	0		4	19	Predation
Black-necked stilt	P04-04	26-Apr	12	38	4	18	Successful
Black-necked stilt	P04-05	29-Apr	11	37	4	23	Predation
Black-necked stilt	P04-06	15-May	6		4	12	Unknown
Black-necked stilt	P05-01	26-Apr	5	25	4	10	Abandoned

TABLE 1
Results of Nest Observations and Se Analysis of Eggs, Kesterson 1998

Species	Location	Date	Embryo ^a		# Eggs	Egg-Se	Fate of Nest
		Collected	Day ^b	Stage	Clutch	DW	
Black-necked stilt	P05-02	26-Apr	8	34	4	2.8	Abandoned
Black-necked stilt	P05-03	26-Apr			2	No egg	Predation
Black-necked stilt	P12-01	5-Apr	3	18	4	4.9	Predation- pond dried
Brewer's blackbird	P01-01	22-May			3	No egg	Unknown
Brewer's blackbird	P02-01	22-May			1	No egg	Abandoned
Brewer's blackbird	P02-02	22-May	1		5	13	Unknown
Brewer's blackbird	P04-01	16-May			1	No egg	Abandoned
Duck (Gadwall)	P01-01	29-Apr	1		11	No data ^c	Predation
Duck (Gadwall)	P03-01	5-Apr	0		4	11	Predation
Duck (Cinnamon teal)	P03-02	3-Jun	3	16	12	3.5	Successful
Duck (Gadwall)	P04-01	7-May	2	8	11	7.6	Predation
Duck (Mallard)	P05-01	5-Apr	0		3	4.2	Predation
Duck (Gadwall)	P05-02	5-Apr	5	26	8	5.0	Predation
Killdeer	140-01	28-Jun	14		4	6.1	Successful
Killdeer	Cmp-01	21-Mar	2	10	4	17	Unsuccessful - flooded
Killdeer	Cmp-02	16-May	2	10	4	5.4	Predation
Killdeer	P01-01	9-Mar			1	No egg	Predation
Killdeer	P01-02	18-Mar				No egg	Predation
Killdeer	P01-03	30-Mar	2	10	1	3.3	Abandoned
Killdeer	P01-04	30-Mar	1	3	2	5.9	Predation
Killdeer	P01-05	7-Apr	2	8	4	11	Predation
Killdeer	P01-06	8-Apr	1	2	3	8.5	Predation
Killdeer	P01-07	7-Apr	2	8	3	3.2	Abandoned
Killdeer	P01-08	7-Apr			1	No egg	Abandoned
Killdeer	P01-09	7-Apr	0		3	5.5	Predation
Killdeer	P01-10	7-Apr	2	10	4	8.0	Predation
Killdeer	P01-11	15-Apr	2	14	4	5.9	Predation
Killdeer	P01-12	10-May	1		4	9.8	Successful
Killdeer	P01-13	22-May	0		2	5.5	Successful
Killdeer	P01-14	31-May	3	16	4	22	Successful
Killdeer	P02-02	7-Apr	1	3	3	8.3	Successful
Killdeer	P02-03	7-Jun			4	No egg	Predation

TABLE 1
Results of Nest Observations and Se Analysis of Eggs, Kesterson 1998

Species	Location	Date	Embryo ^a		# Eggs	Egg-Se	
		Collected	Day ^b	Stage	Clutch	DW	Fate of Nest
Killdeer	P03-01	17-Mar			1	No egg	Predation
Killdeer	P03-02	15-May	2		4	9.9	Predation
Killdeer	P03-03	11-Jul			1	No egg	Predation
Killdeer	P03-05	20-May	10	36	3	15	Successful
Killdeer	P04-01	26-Apr			1	No egg	Predation
Killdeer	P04-02	20-May	0		4	9.4	Predation
Killdeer	P04-03	20-May	4	22	4	19	Predation
Killdeer	P04-04	21-May	1		2	10	Predation
Killdeer	P04-05	22-May	1		4	10	Predation
Killdeer	P05-01	30-Mar	0		2	15	Predation
Killdeer	P05-02	26-Apr			2	No egg	Successful
Killdeer	P05-03	20-Jun	0		2	24	Unknown
Killdeer	P06-01	19-Apr	2	8	4	12	Predation
Killdeer	P07-01	9-Apr	0		1	2.9	Abandoned
Killdeer	P07-02	15-May	0		2	7.9	Predation
Killdeer	P07-03	14-Jun	1		4	8.0	Predation
Killdeer	P09-01	30-Mar	0		1	9.2	Abandoned
Killdeer	P09-02	7-Apr	2	7	3	31	Abandoned
Killdeer	P09-03	15-May	0		4	23	Predation
Killdeer	P09-04	16-May	0		2	14	Successful
Killdeer	P09-05	7-Jun			3	No egg	Predation
Killdeer	P10-01	14-May			1	No egg	Predation
Killdeer	P11-01	7-Apr			3	No egg	Abandoned
Killdeer	P11-02	5-May	14	39	4	8.4	Successful
Killdeer	P11-03	29-Apr	6	28	4	9.0	Predation
Killdeer	P11-04	3-Jun	0		3	7.7	Successful
Killdeer	P11-05	13-Jun	7-8	33	4	4.9	Predation
Killdeer	P12-01	9-Mar	0	2	2	2.9	Successful
Killdeer	P12-02	11-Mar	0	4	4	2.2	Predation
Killdeer	P12-03	17-Mar	4	23	4	1.9	Predation
Killdeer	P12-04	9-Apr	0		3	6.1	Predation
Killdeer	P12-05	29-Apr	7	31	4	6.7	Predation

TABLE 1
Results of Nest Observations and Se Analysis of Eggs, Kesterson 1998

Species	Location	Date	Embryo ^a		# Eggs	Egg-Se	Fate of Nest
		Collected	Day ^b	Stage	Clutch	DW	
Killdeer	P12-06	29-Apr	9	35	4	4.6	Successful
Killdeer	SLD-01	16-Mar	1	8	4	6.6	Successful
Lesser nighthawk	Cmp-01	7-May	10	32	2	6.6	Successful
Lesser nighthawk	P02-01	15-May	4	25	2	12	Successful
Loggerhead shrike	KNWR	2-May	-	-		1.7	Successful
Loggerhead shrike	P01-01	27-Mar	1	3	4	5.1	Predation
Loggerhead shrike	P01-02	7-May	11	36	6	4.5	Successful-chick predation
Loggerhead shrike	P07-01	5-Apr	0		2	5.6	Predation
Loggerhead shrike	P07-02	10-May	1		5	6.0	Successful
Loggerhead shrike	SFGRd	26-Apr	0		2	1.9	Predation
Mourning dove	Cmp-01	21-May			1	No egg	Successful
Mourning dove	P02-01	22-May			2	No egg	Successful
Northern harrier	P04-01	15-Apr	3	8	5	6.2	Predation
Red-tailed hawk	P09	18-Mar	0	0		3.9	Unsuccessful
Red-winged Blackbird	P01-01	15-Apr	0		2	5.6	Successful-chick predation
Red-winged Blackbird	P01-02	15-Apr			4	No egg	Successful-chick predation
Red-winged Blackbird	P01-03	26-Apr	7	32	4	5.5	Successful-chick predation
Red-winged Blackbird	P04-01	29-Apr			4	No egg	Successful-chick predation
Red-winged Blackbird	P04-02	15-May			4	No egg	Successful
Red-winged Blackbird	P05-01	15-Apr			1	10	Abandoned
Red-winged Blackbird	P05-02	15-May			4	No egg	Predation
Red-winged Blackbird	P05-03	15-May			3	No egg	Successful

^a Day and stage follow Hambureger and Hamilton (1951), Hamilton (1952), Hermes and Woodard (1987), and Pisenti et al. (1997)

^b Days are days of incubation. Day 0 is < 1 day of incubation. "R" are eggs that were rotten when collected and are not random eggs.

^c Egg contents lost.

American Avocet

Four nests were found and eggs were collected from each nest in 1998 (Table 2). Selenium concentrations from eggs collected in 1998 are compared to concentrations in the few eggs collected from Kesterson in other years (Table 2). Eggs collected before Kesterson was dewatered and filled in 1988 were higher than those collected in 1998. There were no successful avocet nests at Kesterson in 1998. Three of the nests failed due to predation, probably by coyotes, and one nest was abandoned.

TABLE 2

Se Concentrations (ppm dry weight) in American Avocet Eggs Collected from Kesterson

Year	<i>n</i>	Range	Geometric Mean ^a	Comments
1987	3	37 – 53	45 A	Prior to dewatering and filling of Kesterson
1996	1		2.6	
1998	4	2.5 – 7.9	3.7 B	Ephemeral pools late into the summer

^a Geometric means sharing the same letters are not significantly different ($n \geq 3$, Tukey-Kramer HSD $P \leq 0.05$).

American Kestrel

Ten eggs were collected from eight nest boxes in 1998. Seven random eggs were collected from nest boxes located on Kesterson or along the San Luis Drain (Tables 1 and 3). Two unhatched eggs (NB 01-04, 2.9 ppm and NB 04-05, 5.0 ppm) were from nests where randomly selected eggs had been collected earlier. One egg was collected from an unsuccessful nesting attempt about 4 miles north of Kesterson (NB 140-01, 2.2 ppm). Selenium concentrations from eggs collected in 1998 were similar to those in eggs collected in 1997.

TABLE 3

Se Concentrations (ppm dry weight) in American Kestrel Eggs Collected from Kesterson

Year	<i>n</i>	Range	Geometric Mean ^a	Comments
1997	3	3.1 – 4.0	3.6 A	
1998	7	2.3 – 5.0	3.4 A	Ephemeral pools late into the summer

^a Geometric means sharing the same letters are not significantly different ($n \geq 3$, Tukey-Kramer HSD $P \leq 0.05$).

Barn Swallow

Three eggs were collected in 1998 (Tables 1 and 4). Nests are usually found in the culverts along the south side of Gun Club Road. However, few nests have been found in these culverts since 1994. Only one nest was found in 1995, and two nests were found in 1996 and again in 1997 in the culverts. The eggs collected in 1998 had selenium concentrations similar to concentrations found in swallow eggs collected from Kesterson in other years (Table 4).

TABLE 4

Se Concentrations (ppm dry weight) in Barn Swallow Eggs Collected from Kesterson

Year	<i>n</i>	Range	Geometric Mean ^a	Comments
1988	33	3.8 - 11	6.6	Prior to dewatering and filling of Kesterson
1989	13	4.0 - 7.9	5.6	Kesterson dewatered in fall of 1988, many nest sites (culverts) removed.
1990	9	3.7 - 6.3	5.6	
1991	9	4.1 - 6.8	5.2	
1992	3	4.2 - 6.1	4.8	
1993	4	5.1 - 5.6	5.3	Heavy March rain destroyed some nests

TABLE 4

Se Concentrations (ppm dry weight) in Barn Swallow Eggs Collected from Kesterson

Year	<i>n</i>	Range	Geometric Mean ^a	Comments
1994	5	5.4 - 11	7.5	
1995	1	5.3	-	
1996	1	7.4	-	
1997	2	4.2 - 8.5	6.0	
1998	3	6.0- 7.0	6.6	Ephemeral pools late into the summer

^a There was no significant difference in Se concentrations among years.

Barn Owl

In 1996 a nest box was placed in the compound adjacent to Pond 4 and in 1997 barn owl nest boxes were placed in Ponds 1, 3, and 5. Eggs were collected from these nest boxes in 1998. During 1998, there were seven nesting attempts in these four nest boxes and six eggs were collected (Tables 1 and 5). Eggs were collected from three nests that were later abandoned and there were signs of nest predation (possibly a raccoon) at one nest.

TABLE 5

Se Concentrations (ppm dry weight) in Barn Owl Eggs Collected from Kesterson

Year	<i>n</i>	Range	Geometric Mean	Comments
1997	1		8.0	
1998	6	2.4 – 6.7	3.4	Ephemeral pools late into the summer

Black-necked Stilt

Twenty nests were found and nineteen eggs were collected in 1998 (Tables 1 and 6). Hatching success was low in stilts (15 percent); 65 percent of nests found were lost to predation, 15 percent were abandoned, and cause of failure for five percent of the nests could not be determined. One egg collected from Pond 4 (19 ppm selenium) showed "positive development" (cell division with no embryo formed). Black-necked stilts have not been found nesting at Kesterson since 1987, before it was dewatered and filled in 1988 (Table 6).

TABLE 6

Se Concentrations (ppm dry weight) in Black-necked Stilt Eggs Collected from Kesterson

Year	<i>n</i>	Range	Geometric Mean	Comments
1987	2	20 – 23	21	Prior to dewatering and filling of Kesterson
1998	19	2.8 – 42	12	Ephemeral pools late into the summer

European Starling

We attempted to collect all starling eggs prior to hatching to increase nest box use by American kestrels and to limit reproduction by starlings (a non-native species). Starling nesting also was discouraged at Kesterson by removing nesting material from nest boxes when it was found, but six clutches were laid in nest boxes and eggs were analyzed for selenium from each clutch (Table 7). Starlings are probably a good feeding-guild surrogate for western meadowlarks (a common native species). All of the eggs examined contained viable and normal embryos. Selenium concentrations in starling eggs collected in 1998 were significantly different those collected in 1997 (Table 7).

TABLE 7
Se Concentrations (ppm dry weight) in European Starling Eggs Collected from Kesterson

Year	<i>n</i>	Range	Geometric Mean ^a	Comments
1991	1	2.8	2.8	
1996	30	1.5 - 13	3.7 A, B	First year that nest boxes were available
1997	23	2.0 - 7.2	3.4 A	All eggs removed prior to hatching
1998	6	4.8 - 10	6.2 B	All eggs removed prior to hatching

^a Geometric means sharing the same letters are not significantly different ($n \geq 3$, Tukey-Kramer HSD $P \leq 0.05$).

Killdeer

Forty-one killdeer eggs were collected from 53 nests that were found on Kesterson (Tables 1 and 8). Of the 41 nests found on Kesterson, 36 were found along the road on the west side of the San Luis Drain (the east side of Kesterson), 12 were found on interior roads within Kesterson, two were found in Reclamation's compound between Pond 4 and the Fremont Canal, and three were found on the perimeter road on the west side of Kesterson. Killdeer nests were found from March through July, 1998: 12 nests were found in March, 18 nests were found in April, 15 nests were found in May, seven were found in June, and one nest was found in July. Of the nests found on Kesterson, 13 (22 percent) were found empty at the time the eggs were expected to hatch with no signs of predation and were assumed to have been successful. Thirty-one nests (61 percent) were unsuccessful due to predation, seven nests (14 percent) were abandoned, one nest (2 percent) was lost due to flooding, and the fate of one nest was not determined. Of the 13 successful killdeer nests only two were located in the interior or western parts of Kesterson. Eighty percent of nests found interior or on the west-side were lost to predation compared to 53 percent of east-side killdeer nests. The only nests that were abandoned were along the east-side levee road.

Selenium concentrations in the killdeer eggs collected from Kesterson ranged from 1.9 to 31 ppm, with concentrations equal to or greater than 10 ppm in 13 eggs, all of which were collected later in the season (i.e., from early April to early June). The mean concentration of all killdeer eggs collected from Kesterson during 1998 was similar to concentrations in killdeer eggs collected in all years since Kesterson was filled and dewatered (1989 through 1997), and significantly lower than that of killdeer eggs collected in 1988 (Table 8).

TABLE 8
Se Concentrations (ppm dry weight) in Killdeer Eggs Collected from Kesterson

Year	<i>n</i>	Range	Geometric Mean ^a	Comments
1988	24	6.5 - 58	15.8 A	Prior to dewatering of Kesterson
1989	9	3.5 - 15	6.4 B	Kesterson dewatered in fall of 1988
1990	11	2.9 - 20	7.0 B	
1991	7	3.1 - 12	5.4 B	
1992	13	2.5 - 28	8.5 A, B	
1993	2	11 - 17	13.7	Heavy March rain interrupted nesting
1994	12	2.8 - 11	5.6 B	
1995	12	2.3 - 13	5.7 B	
1996	20	2.2 - 13	5.4 B	
1997	29	1.8 - 64	5.6 B	Interior and west-side nests found
1998	41	1.9 - 31	8.0 B	Ephemeral pools late into the summer

^a Geometric means sharing the same letters are not significantly different ($n \geq 3$, Tukey-Kramer HSD $P \leq 0.05$).

Waterfowl

Few waterfowl nested at Kesterson. Therefore, eggs from mallard (*Anas platyrhynchos*), gadwall (*Anas strepera*), and cinnamon teal (*Anas cyanoptera*) were combined as "duck eggs" (Table 1). Five duck nests were found in 1998: three in April, one in May, and one in June and eggs were analyzed from these nests (Tables 1 and 9). Four of the duck nests found in 1998 were lost to predation and one was successful. Fewer waterfowl nests have been found at Kesterson since it was dewatered in the fall of 1988 and few of those nests that have been found were successful despite relatively low selenium concentrations in most analyzed eggs. There were no significant differences in selenium concentrations found in duck eggs collected from 1988 to 1998 (Table 9).

TABLE 9
Se Concentrations (ppm dry weight) in Duck Eggs Collected from Kesterson

Year	<i>n</i>	Range	Geometric Mean ^a	Comments
1988	15	3.9 - 31	12	Prior to dewatering of Kesterson
1989	1	3.7	-	Kesterson dewatered in fall of 1988
1990	2	1.7 - 3.1	2.3	
1992	1	1.1		
1993	4	1.9 - 15	5.8	Heavy March rain
1994	1	7.7	-	
1995	3	4.5 - 16	8.9	
1996	3	1.6 - 5.3	2.8	
1997	3	1.6 - 3.4	2.4	
1998	5	3.5 - 11	5.7	Ephemeral pools late into the summer

^a There was no significant difference in Se concentrations among years.

Loggerhead Shrike

Loggerhead shrike (*Lanius ludovicianus*) eggs were collected for the first time in 1998. Four nests were discovered on Kesterson and two nests were found off-site prior to chicks hatching; one egg was collected from each nest. Two other nests were found after chicks hatched. Of the six nests found containing eggs, three were lost to predators and three (two on-site and one off-site) hatched and fledged young. Selenium concentrations in eggs collected from nests on Kesterson (two from Pond 1 and two from Pond 7) ranged from 4.5 to 6.0 ppm selenium (geometric mean = 5.3 ppm).

Lesser Nighthawk

Two lesser nighthawk (*Chordeiles acutipennis*) nests were found and monitored in 1998 (Table 1). One nest was found on the gravel roadway along the San Luis Drain adjacent to Pond 1 and the other on a gravel area in the Reclamation trailer compound (Compound). Both nests had two eggs in them when they were discovered and one egg was collected from each nest. Both nests were lost to predators prior to the eggs hatching. Selenium concentrations in the eggs analyzed were higher than the selenium concentrations found in the nighthawk eggs collected from Kesterson in 1992 and 1997 (Table 10).

TABLE 10

Se Concentrations (ppm dry weight) in Lesser Nighthawk Eggs Collected from Kesterson

Year	n	Range	Geometric Mean ^a	Comments
1992	1		4.9	
1997	1		4.3	
1998	2	6.2 – 12	8.9	Ephemeral pools late into the summer

^a There was no significant difference in Se concentrations among years.

Other Nests

Other nests that were found at Kesterson in 1998 were red-tailed hawk (*Buteo jamaicensis*), northern harrier (*Circus cyaneus*), great horned owl (*Bubo virginianus*), red-winged blackbird (*Agelaius phoeniceus*), and Brewer's blackbird (*Euphagus cyanocephalus*). A red-tailed hawk egg was found below the nest located on a power pole in Pond 9 that was occupied by great horned owls. We assume that this egg was laid on the road because the hawk was evicted from the Pond 11 nest (where red-tailed hawk have nested or attempted to nest in other years). A red-tailed hawk nest was located on a power pole at the east end of Gun Club Road where a pair had attempted to nest in 1996 and 1997. This nest was not very stable and it was blown over by high winds before any eggs had been laid in 1997. In 1998, the red-tailed hawk pair successfully hatched one egg and raised a chick until it was lost to predation after about two weeks. Because this nest is located on a live power pole (and the poor success of red-tailed hawks nesting on Kesterson in recent years) no egg was collected from this nest. A single northern harrier nest was found in Pond 4 and an egg was collected and analyzed for selenium (6.2 ppm selenium). This nest was lost to predation (coyote) two weeks after the egg was collected. A great horned owl nest was found on a power pole located on the San Luis Drain road in Pond 9 in the vicinity where red-tailed hawks and great horned owls have nested and attempted to nest in other years. The great horned owls

raised two chicks until they were about three weeks old. At this time the female parent was found dead at the bottom of the nest pole. Necropsy revealed that she had been killed by another great horned owl (based on talon injuries found on the breast of the owl). Red-winged and Brewer's blackbird nests were found and eggs were collected from abandoned nests. Many nests were apparently lost to predation both at the egg and chick stage.

Discussion

Generally, nesting by wetland-associated species was higher than in previous years and nesting by terrestrial species was lower. Although selenium levels in most eggs were elevated above background levels, no seleno-toxic effects were observed in 1998. Geometric mean selenium concentrations in eggs varied among species collected from Kesterson in 1998 (Table 11). Black-necked stilts that nested at Kesterson in 1998, because of the persistence of rainwater pools on-site, had higher selenium concentrations in eggs than did avocets, kestrels, and barn owls. Killdeer egg selenium concentrations were higher than the concentration in kestrel eggs. The overall success of nests that were found at Kesterson in 1998 was 32 percent. Almost half (49 percent) of all the nests found in 1998 were lost to predators and 14 percent were abandoned by the adults (Table 12).

TABLE 11

Summary of Se Concentrations (ppm dry weight) in Bird Eggs Collected from Kesterson Compared by Species, 1998

Species	<i>n</i>	Geometric Mean ^b	Range
American avocet	4	3.7 A, C	2.5 – 7.9
American kestrel	7	3.4 A	2.3 – 5.0
Barn swallow	3	6.6 A, B, C	6.0 – 7.0
Barn owl	6	3.4 A, C	2.4 – 6.7
Black-necked stilt	19	12 B, C	2.8 - 42
Brewer's blackbird	1	13	
Duck	5	5.7 A, B, C	3.5 - 11
European starling	6	6.2 A, B, C	4.8 – 10
Killdeera	41	8.0 B, C	1.9 – 31
Lesser nighthawk	2	8.9	6.6 – 12
Northern harrier	1	6.2	
Red-tailed hawk	1	3.9	
Red-winged blackbird	3	6.8 A, B, C	5.5 - 10

^a Only eggs from nests found on or adjacent to Kesterson are included in this table.

^b Geometric means sharing the same letters are not significantly different ($n \geq 3$, Tukey-Kramer HSD $P \leq 0.05$).

TABLE 12
Fate of Nests Found at Kesterson, 1998

Species	Abandoned	Predation	Unsuccessful	Successful	Unknown	Total Nests
American avocet	1	3	4	0		4
American kestrel	1	1	2	6		8
Barn owl	3	1	4	3		7
Barn swallow				3		3
Black-necked stilt	3	13	16	3	1	20
Brewer's blackbird	2		2	0	2	4
Duck		5	5	1		6
Great horned owl		1	1			1
Killdeer	7	31	39 ^a	12	2	53
Lesser nighthawk			0	2		2
Loggerhead shrike		2	2	2		4
Mourning dove			0	2		2
Northern harrier		1	1	0		1
Red-tailed hawk		1	1	0		1
Red-winged blackbird	1	1	2	6		8
Total nests	18	59	77	40	6	124

^aOne killdeer nest unsuccessful due to flooding

To be sure that sampling represented selenium concentrations for Kesterson, a random egg was collected from almost every nest found. Eggs were collected early during the incubation period from most nests so that as many nests as possible would be sampled (i.e., few nests were not sampled due to predation of the nest prior to collecting an egg). The goal was to provide an accurate representation of selenium concentrations for the entire site and help to identify possible "hot spots" for management or additional sampling. However, collecting early during the incubation period increases the number of viable eggs (i.e., fertile eggs or those with living embryos) because there is potentially higher mortality later during incubation and embryo teratogenesis is more likely to be found in later-stage embryos.

To address this problem of collecting eggs early enough to avoid losses from predation and also collecting samples that are likely to show embryo mortality or teratogenesis (if it is occurring), two eggs were collected from each shorebird nest (and some other species nests). The second egg was incubated until the embryo was in the last third of development and evaluated for abnormalities. (Results of this study are not yet available and will be presented in a supplement to this report). However, predation is typically high in killdeer nests (Tables 1 and 12). Many of the high-selenium killdeer nests found in 1997 and 1998

were in the interior of the site where predation may be higher. This may bias the results if a disproportionate number of high-selenium nests experience predation.

Since 1993, when heavy rain early in the nesting season (for killdeer) interrupted nesting, the number of killdeer nests found at Kesterson has increased, and nests were found in higher numbers in 1998 than in any other year that they were monitored. Nest initiation was later than in 1997, but earlier than in 1995 and 1996, and nesting ended later in 1998 than in other years (Figure 1). Onset of killdeer nesting seems to be partially determined by rainfall (Figure 2). 1997 was exceptionally dry in February and March and some killdeer began nesting by February 26. However, only a few nests are started early and most nests are initiated in mid-March. Fifty percent of the nests had been started by the first half of May in 1995 and by the end of April in 1996–1998. The proportion of killdeer observed during the breeding season (February – June) and nests found were roughly proportional to the number of killdeer using Kesterson (about 2 killdeer for each nest), based on daily use surveys during the breeding period (February – June). This is illustrated in Figure 3. However, in 1996 and 1997 the ratio was less than two-to-one. In 1998, the ratio was again about two (2.2) killdeer per nest. One reason why more nests were found on Kesterson than could be accounted for by killdeer population in 1996 and 1997 may have been that some of the killdeer were foraging in the Kesterson National Wildlife Refuge (KNWR) and other adjacent areas and used Kesterson for nesting. The number of killdeer foraging and nesting at Kesterson has been increasing since 1994 (Figure 3). During 1998, the number of killdeer foraging on Kesterson was more than twice as high as other years and nesting on Kesterson was 1.8 times higher than in any other years. Rainwater pools persisted at Kesterson, and surrounding areas also remained flooded far into the breeding season, possibly providing increased food resources. Another possible reason for the higher number of killdeer and killdeer nesting is that the wet conditions and plant succession changed the vegetation structure, so there are more areas with short vegetation suitable for killdeer nesting within Kesterson.

There does not appear to be a consistent temporal trend of selenium concentration during the nesting season. In 1998, killdeer collected in May had significantly higher mean selenium concentrations than eggs collected in March. In 1997, eggs collected during the early part of the nesting season (i.e., February – April) had significantly higher selenium concentrations than those collected from May – June. The percentage of nests in 1998 found in the interior or west side of Kesterson (33 percent) was about the same as that found in 1997 (30 percent). Eggs collected from interior nests in 1998 had a higher geometric mean selenium concentration (GM = 12 ppm, $n = 10$, range = 5.4 – 19) than those from along the east side of Kesterson (GM = 6.9 ppm, $n = 32$, range = 1.9 – 31).

FIGURE 1
Cumulative Probability of Clutch Initiation by Killdeer

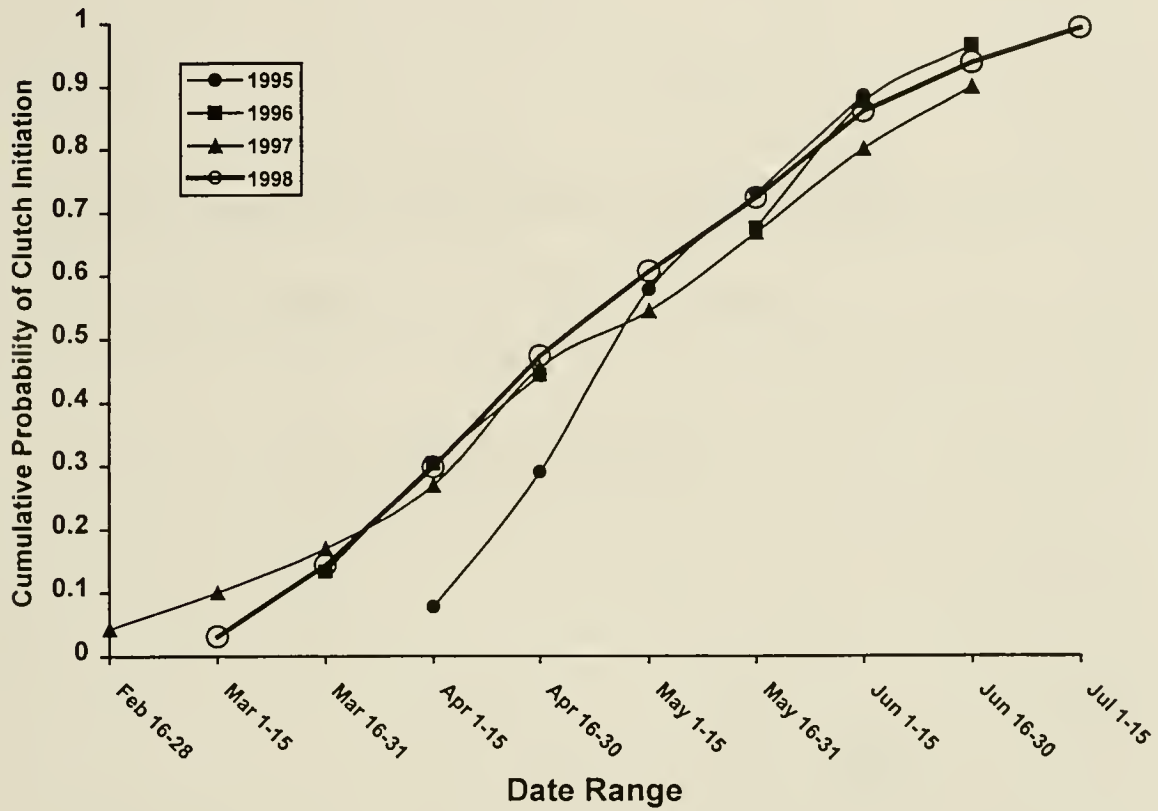


FIGURE 2

Rainfall (inches) and Killdeer Nests Started from February 1 Through March 30, 1996–1998.

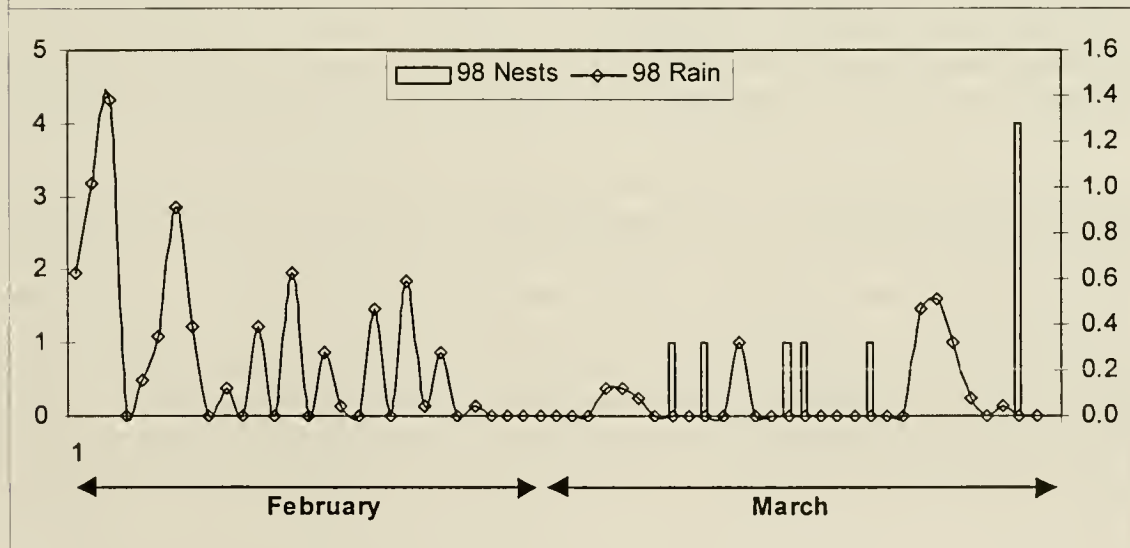
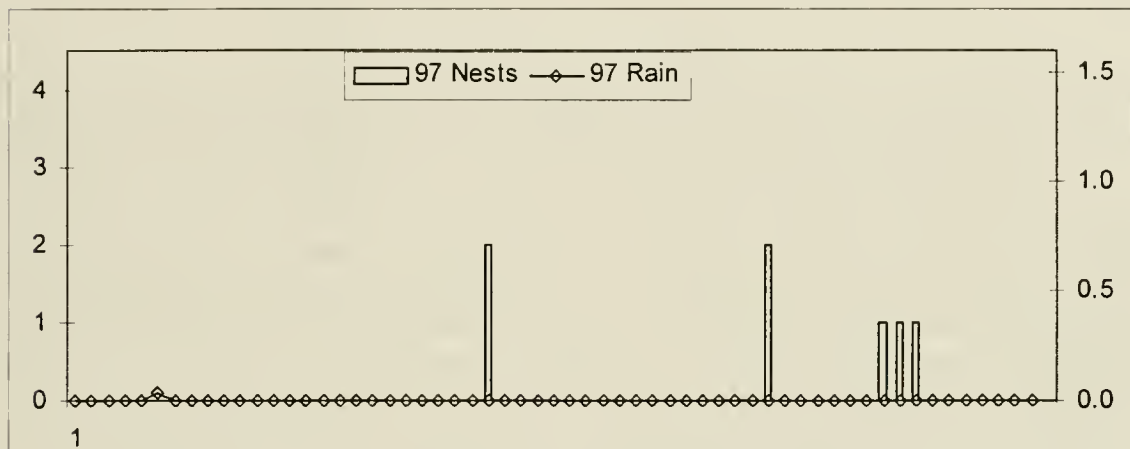
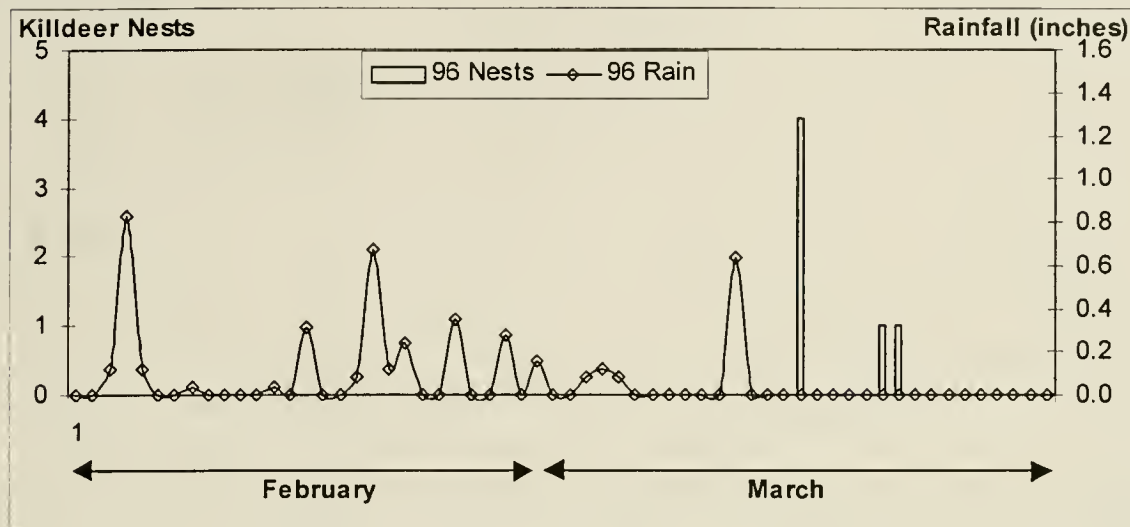
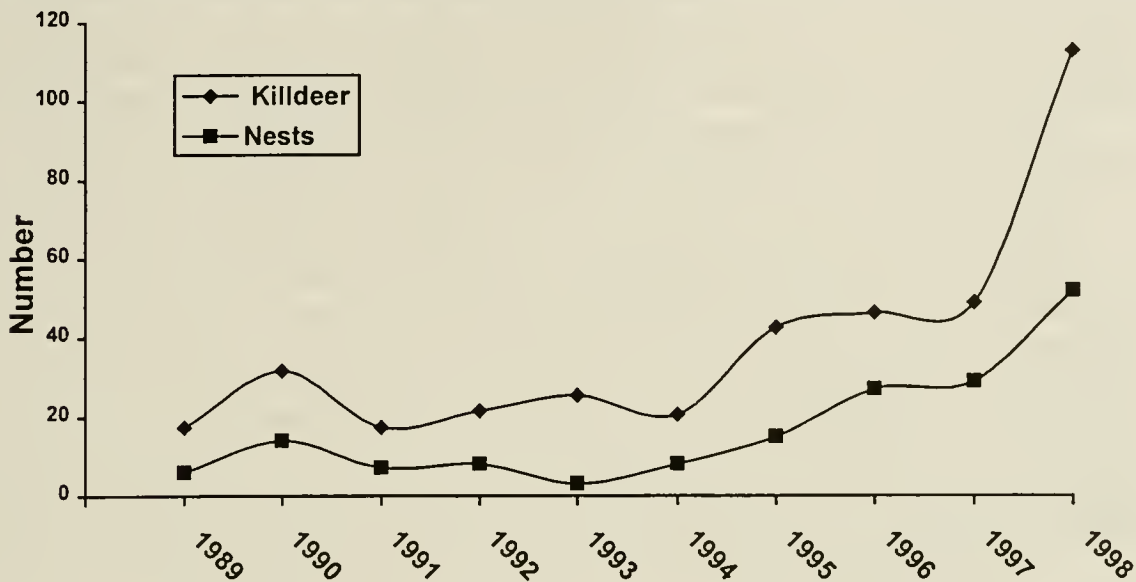


FIGURE 3

Number of Killdeer Observed (Daily Use) During the Breeding Season (February through June) and Number of Nests Found



Poor nesting success for ducks and shorebirds may be due to physical factors such as the loss of habitat when the ephemeral pools disappear (this has been observed in other years). In 1998, when rainwater pools persisted into the normal nesting season (for many shorebirds), at least two species that do not typically nest at Kesterson nested there (i.e., stilts and avocets). As in other years, there was a high percentage of nest predation among ground-nesting species. Prior to dewatering of Kesterson in 1988, many upland areas were at least partially protected from predators because they were surrounded by water during the reproductive period and the types of plants were, for the most part, low-growing species. Since Kesterson was dewatered, conditions for nesting for the various bird species have changed and, in general, selenium concentrations in eggs have gone down (see Tables 2 through 9). Many factors have contributed to changing nesting conditions at Kesterson. These factors include variations in climatic conditions (e.g., rainfall and temperature), the conversion of Kesterson from a wetland to a terrestrial ecosystem, successional changes in vegetation causing plant species changes and structural changes in habitat, and disturbance during the reproductive season from monitoring and management activities.

Nest sites on Kesterson are limited for some species. Birds such as mallards and black-necked stilts now have less wetland habitat to attract them. Barn swallows (*Hirundo rustica*) that use concrete culverts for nesting are limited by the number of these structures left at Kesterson (many of these culverts were removed during filling of Kesterson). Also, many barn swallow nests have fallen down during heavy rainfalls and have not been rebuilt. Killdeer prefer open areas around their nests, and the tall weeds and grasses that grow at Kesterson in most years make much of the interior of the site unsuitable for killdeer or many other ground-nesting species. However, conditions in 1997 and 1998 were more suitable for nesting in the interior possibly due to the low-growing vegetation observed into late in the summer.

Of the killdeer eggs collected at Kesterson, the percent of nests lost to predation (60 percent) was higher than the percent of successful nests (23 percent). This was also higher than the predation rate of 36 percent from 1984 – 1985 at Kesterson (Ohlendorf et al. 1989). Killdeer eggs collected from the interior and west side of Kesterson had a geometric mean of 12 ppm and these eggs had a higher geometric mean selenium concentration ($P = 0.0425$) than those collected along the San Luis Drain on the east side of Kesterson (GM = 6.9 ppm). The geometric mean selenium concentration in killdeer eggs (8.0 ppm) and black-necked stilt eggs (12 ppm) were within the suggested level of concern for clutch viability for stilts (6 - 5 ppm, NIWQP 1998), many of the eggs were above the concentrations expected to produce embryo toxicity and teratogenesis. Although hatching success was low due to predation and abandonment, selenium-related effects in bird reproduction at Kesterson were not found and have not been found since the filling operation. Many eggs continue to have selenium levels above median back-ground levels of 1.9 ppm and 74 of the 98 eggs (76 percent) collected from nests at Kesterson had selenium concentrations above the 5.0 ppm maximum level for above background contamination (NIWQP 1998). Twenty-eight eggs (29 percent) were above the suggested avian threshold for reproductive impairment of 10 ppm (Heinz 1996). None of the eggs collected in 1998 were above the threshold level for embryo teratogenesis for tolerant taxa (74 ppm; NIWQP 1998). One stilt nest lost to predators contained an egg (42 ppm) that was high enough to expect that embryo teratogenesis could occur (based on IC_{10} of 23 ppm for sensitive taxa; NIWQP 1998).

The preliminary results of the egg incubation study conducted at UC Davis did not find developmental abnormalities the embryos incubated (Table 13). Four percent of the embryos died during incubation and about 8 percent did not develop and were possibly infertile.

TABLE 13
Kesterson Eggs Incubated Through the Late Stages of Development at UCD

Species	<i>n</i>	Live-Normal	Dead-Normal	No Development ^a
American avocet	1	1	1	0
Black-necked stilt	16	14	0	2
Duck	3	2	1	0
Killdeer	22	22	0	0
European starling	8	6	0	2
All Eggs	51	45	2	4

^a No development includes infertile and suspected infertile eggs.

Preliminary results of analysis of egg data for black-necked stilts and killdeer (Appendix A) show that although the concentrations of selenium found in some of these eggs is sufficient to expect selenium-induced selenium toxicity, only a low incidence is expected. The results of the analyses conducted on teratogenesis and egg viability in stilt and killdeer eggs are summarized here and the complete analyses are provided in Appendix A. Analyses using the 1998 stilt egg selenium data predicted a probability of 1.62 percent for teratogenesis. Therefore, out of the entire population of stilts nesting at Kesterson in 1998 (i.e., estimated

80 eggs produced), 1 or 2 eggs would be expected to produce a teratogenic embryo. Similar analysis of the killdeer data predicted a probability of 0.7 percent for teratogenesis. At this predicted rate, 1 or 2 teratogenic embryos would be expected to be produced by the population (i.e., estimated 208 eggs produced) of nesting killdeer at Kesterson. Low levels of inviability were predicted for both stilts and killdeer and the likelihood of encountering a nest with more than one inviable egg is low. After accounting for the normal background rates of egg inviability, the egg-wise incidence of inviability for stilts was calculated as 2.2 – 4.3 percent (i.e., estimated 1.7 out of 80 eggs produced) for stilts and 2.2–3.4 percent (i.e., estimated 2.5 out of 208 eggs produced) for killdeer. The results of the studies being conducted at UC Davis (incubating duplicate eggs collected from nests) may provide some additional information on the potential for reproductive problems for birds at Kesterson.

There are few nest sites for red-tailed hawks and great horned owls at Kesterson and the available sites (e.g., power poles) do not afford the same protection from severe weather conditions as do natural nest sites (e.g., trees). Other than in the nest boxes that we provided for barn owls and kestrels, only three raptor nests were found at Kesterson this year (one each red-tailed hawk, northern harrier, and great horned owl). All three of these nests failed due to predation at different times in the nesting cycle. The ultimate cause of these nest failures may have been partially due to the weather conditions in spring. Raptors, such as Swainson's hawks in other parts of the Central Valley also had poor nesting success (James Estep, Michael Bradbury, and Richard Anderson, Swainson's Hawk Technical Action Committee biologists). At Kesterson, the great horned owl and red-tailed hawk attempts failed late in the nesting cycle. These nest failures may have occurred because the birds had to forage long distances away from the nests due to the large areas covered by water and limited food resources (indicated by low small mammal trapping success during the breeding period), exposing themselves and their nestlings to greater risk.

As in 1997, there were at least three pairs of red-tailed hawks that remained at Kesterson through the breeding season, but only two nesting attempts were made. It is not known why these pairs did not nest this year and it is unusual for paired red-tailed hawks to remain in an area without nesting. However, red-tailed hawks did not nest in the tree-nest in KNWR adjacent to Kesterson where a pair successfully nested and fledged chicks in 1997. This and anecdotal information from other raptor biologists indicates that 1998 was a poor year for raptor nesting in the Central Valley possibly due to the inclement weather that affected factors such as food resources and availability of suitable nest sites.

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8. Selenium in Wild Birds

Introduction

Early successional habitat at Kesterson supports vertebrate and invertebrate prey items utilized by raptors and other predatory birds. Avian predators are potentially good terrestrial indicator species because they are common at Kesterson, their foraging ranges can be estimated, and selenium concentrations are relatively high in vertebrate and invertebrate prey compared to plants. Also, many are easily studied through reproduction because they are tolerant of disturbance and they have a long development and nestling stages. Avian predators may be sensitive to selenium at dietary levels found at Kesterson (i.e. lower fertility, Santolo et al. 1999; decreased body condition, J. T. Yamamoto and G. M. Santolo, in preparation), based on studies using captive American kestrels (*Falco sparverius*). However, studies with captive and wild birds (e.g., Heinz 1996, NIWQP 1998) suggest that sensitive aquatic species (e.g., mallards [*Anas platyrhynchos*] and black-necked stilt [*Himantopus mexicanus*]) accumulate and transfer selenium to eggs to a greater degree than do some carnivorous species (e.g., black-crowned night-herons [*Nycticorax nycticorax*; Smith et al. 1988], screech-owls [*Otus asio*; Wiemeyer and Hoffman 1996], and American kestrels (Yamamoto et al. 1998).

A previous risk assessment for Kesterson produced exposure models that predicted selenium concentrations in various biota, including the diets of red-tailed hawk (*Buteo jamaicensis*) and northern harrier (*Circus cyaneus*), over a 20-year period (Ohlendorf and Santolo 1994, Santolo 1994). Based primarily on known concentrations of selenium in prey species as well as estimated time spent foraging at Kesterson, predicted selenium concentrations in the diets of these avian predators were not expected to be high enough to cause significant risks. However, few measurements of selenium in these species themselves were available at the time to develop model predictions. Wild predatory birds were sampled at Kesterson and other locations in California to better characterize the exposure of these and other terrestrial birds to selenium, and to verify prior exposure model predictions for Kesterson.

Objectives

The objective of the wild bird sampling and analysis was to identify the selenium levels in wildlife found at Kesterson.

Study Area

Lands surrounding Kesterson, the primary study area, for an approximate 16-km radius (generally bounded by the Cities of Stevinson, Gustine, Los Banos, and Santa Nella) represented another study area (the "Kesterson Area") that contained primarily agricultural lands (row crops, orchards, and pasture) and seasonal wetland habitats. Some of those pastures and seasonal wetland habitats had historically been irrigated with selenium-containing agricultural drainwater (Presser and Barnes 1985). Other study areas were

located approximately 200km north of Kesterson in the counties of Yolo, Solano, and San Joaquin (referred to as "Sacramento Valley"; 38°N, 121°W); and approximately 130km northwest of Kesterson near Suisun Marsh ("Bay-Delta"; 38°N, 122°W). Except for the Bay-Delta study area (which was mostly wetland), habitats in these areas were mostly agricultural, similar to those of the Kesterson Area. Limited trapping for American kestrels also was conducted during November 1995 in agricultural areas adjacent to the Salton Sea (Imperial County), located in the Imperial Valley of California, approximately 1,100km south of Kesterson (33°N, 115°W).

Methods

Field Sampling and Selenium Analysis

Year-round trapping efforts were carried out during the 1994 to 1998 study period. Samples were collected in all months except January, March, and April 1994, February and March 1995, February and June 1996, September 1997, and August and September 1998. Species sampled were barn owl (*Tyto alba*), red-tailed hawk, American kestrel, loggerhead shrike (*Lanius ludovicianus*), northern harrier, great horned owl (*Bubo virginianus*), western screech-owl (*Otus kennicottii*), and burrowing owl (*Athene cunicularia*). In addition to adult and immature birds, nestlings of kestrels, loggerhead shrikes, northern harriers, and barn owls also were sampled. Searching for birds to trap was done primarily from a vehicle. Birds were captured with a bal-chatri or modified Potter's trap using live mice as lures and dho-ghaza using a great horned owl as a lure for nesting birds (Bub 1991). Bal-chatri traps were used in trapping attempts for birds that were considered capable of seeing a trap (up to about 100 m from the road) thrown from the vehicle onto the road shoulder. During 1998, six white-crowned sparrows (*Zonotrichia leucophrys*) and one western kingbird (*Tyrannus verticalis*) were also captured. White-crowned sparrows were captured using a walk-in treadle trap baited (Bub 1991) with seed and the western kingbird was captured by dho-ghaza while attempting to capture a red-tailed hawk¹. After capture, birds were weighed and, when possible, aged and sexed and fitted with a federal (aluminum) band. Up to 0.5 mL of blood was drawn from a wing or jugular vein using a heparanized 1 mL insulin syringe. Blood was stored in 3 mL cryogenic vials (Nalgene, Inc.) and frozen ≤ -40° C for selenium analysis. All measurements and blood sampling were done at the capture site, where birds were released immediately after processing was complete.

Invertebrates and mammals were collected from February through June each year for selenium-monitoring purposes from all areas of Kesterson using pitfall traps and sweep nets for invertebrates and live- and kill-traps for small mammals.

Laboratory Analyses

Whole blood samples and prey items were analyzed for total selenium by two commercial laboratories. Laboratory and Environmental Testing (Columbia, Missouri) sample preparation consisted of lyophilization, followed by homogenization, and sequential acid

¹ Passerine (sparrow and kingbird) blood-Se is presented in Table 1 but will not be discussed here. This data along with western meadowlark (*Sturnella neglecta*) and killdeer (*Charadrius vociferus*) tissue selenium data will be reported after these data have been analyzed in a separate report.

digestions (nitric acid followed by hydrochloric acid). Total selenium concentrations were determined using hydride generation atomic absorption spectroscopy. Quality control included at least 10 percent duplicates, 10 percent spikes, 5 blanks, and 5 percent reference samples. Lyophilization data were used to calculate percent moisture in all samples. The California Veterinary Diagnostic Laboratory (Davis, California) used hydride vapor generation inductively coupled argon plasma spectrometry (Tracy and Möller 1990). Twenty duplicate samples were analyzed and compared between laboratories. A linear regression analysis produced an r^2 value of 0.96 ($P < 0.0001$) for the duplicate samples, indicating that results were comparable both between laboratories and analytical techniques. All selenium concentrations in blood are expressed as ppm on a dry weight basis.

Egg-Se Estimation

Concentrations of selenium in eggs (egg-Se) were estimated for sampled birds, using a blood-to-egg selenium concentration relationship established in captive kestrel studies (Santolo et al. 1999) and assuming the transfer factor to be the same for other predatory birds. This relation is described by the equation $y = 0.136 + 2.272 x$, where y = selenium concentration in eggs and x = selenium concentration in parent blood.

Results and Discussion

Capture Frequencies

Numbers of individuals captured are shown by species and study area in Table 1. Kestrels, red-tailed hawks, and barn owls were the most frequently captured species in the three main study areas, reflecting their relatively high local abundance over all months of the year. Higher numbers of these species were captured at Kesterson compared to other areas, largely due to the increased trapping effort made for this study area. Capture success was also influenced by trapping method, in that these three species tend to be more readily captured on bal-chatri traps than are shrikes, harriers, and Other Owl species. No harriers or owls, other than barn owls, were obtained for sampling in the Kesterson Area, and only kestrels were trapped in the Salton Sea area. Kestrels, red-tailed hawks, barn owls, and loggerhead shrikes are desirable as indicator species because, as a group, they represent a range of raptor foraging niches, and because blood-Se in resident individuals (i.e., individuals that winter and/or stay at Kesterson through the reproductive period) of these species is more likely to reflect local levels than the blood-Se found in transient (i.e., migrating or dispersing) individuals.

In 1998 within species comparisons, blood-Se was significantly higher in kestrels and loggerhead shrikes, from Kesterson than those from the Kesterson Area (Table 1). Loggerhead shrikes from both Kesterson and the Kesterson Area had higher blood-Se than shrikes from the Sacramento Valley and Bay-Delta study areas. Blood-Se in kestrels from Kesterson was similar to concentrations in kestrels from the Sacramento Valley and significantly higher than Bay-Delta kestrels (Table 1). When blood-Se within species was compared between sample periods, only kestrels were significantly higher in 1998 than

TABLE 1

Blood-Se concentrations (ppm dry weight) for birds collected from various locations in California. Number of samples (n), range of blood-Se (Range), and geometric mean selenium concentrations (GM) are shown.

Species and Location	1994 – 1997			1998		
	n	Range	GM ^a	n	Range	GM ^a
<i>American kestrel</i>						
Kesterson	39	2.0 – 12	4.0 A	55	1.5 – 28	5.4 A
Kesterson Area	44	1.0 - 8.2	2.5 B	14	1.5 – 3.0	2.1 B
Salton Sea	14	1.6 - 4.1	2.5 B			
Sacramento Valley	17	1.0 – 6.5	2.8 B	5	1.9 – 7.3	3.3 A,B
Bay-Delta				4	1.5 - 2.5	1.9 B
<i>Red-tailed hawk</i>						
Kesterson	44	2.1 – 8.7	3.9 A			
Kesterson Area	27	1.6 – 4.7	2.7 B	5	1.7 – 3.0	2.5 A
Sacramento Valley	8	2.0 – 3.9	2.9 A,B	3	2.4 – 4.1	3.0 A
Bay-Delta	4	1.9 – 2.9	2.4 A	4	1.9 – 2.9	2.4 A
<i>Northern harrier</i>						
Kesterson	6	6.3 - 15	9.4			
Sacramento Valley	2	2.0 - 3.8	2.8			
<i>Barn owl</i>						
Kesterson	82	1.5 – 12	4.3 A	33	2.3 – 10	4.4
Kesterson Area	14	1.7 – 5.2	2.4 B	1		1.9
Sacramento Valley	7	3.0 – 3.8	3.3 A,B			
<i>Other owls</i>						
Kesterson	3	6.1 – 11	8.7			
Sacramento Valley	2	3.5 – 4.5	4.0			
<i>Loggerhead shrike</i>						
Kesterson	13	4.9 – 20	11 A	16	7.5 – 38	13 A
Kesterson Area	4	7.6 – 16	11 A	4	5.9 – 8.6	6.5 B
Sacramento Valley	4	3.4 – 15	6.1 B	4	2.4 – 3.6	2.9 C
Bay-Delta				5	2.5 - 3.7	3.1 C
<i>White-crowned sparrow^b</i>						
Kesterson				6	7.4 – 33	18
<i>Western meadowlark^b</i>						
Kesterson				8	7.8 – 18	12
<i>Western kingbird^b</i>						
Kesterson				1		64
<i>Killdeer</i>						
Kesterson				5	7.6 – 57	30

Note: Mean of percent moisture in blood samples was 80.8% and ranged from 67.6 to 91.0%.

^a Within species, GM not sharing the same letter are significantly different ($n \geq 3$; $P \leq 0.05$).

^b White-crowned sparrow, western meadowlark, western kingbird, and killdeer are included for comparison to other blood levels and are not included in analysis.

1994 – 1997. This may be due to the higher number of resident breeding kestrels and their chicks that were at Kesterson since 1997.

When data for all species were combined, mean blood-Se in birds from Kesterson (5.2 ppm) was significantly higher than in birds from the Kesterson Area (2.7 ppm), Sacramento Valley (3.2 ppm), Bay-Delta (2.5 ppm), or Salton Sea (2.5 ppm).

Both individual and combined species blood-Se data are in agreement with current monitoring data from Kesterson showing consistently high levels of selenium in raptor prey species (Table 2). Background selenium concentrations in mammals (whole body) average < 2 ppm (NIWQP 1998). Blood-Se of avian predators should be approximately equal to concentrations of selenium in their diet, based on data from captive kestrels fed either pure selenomethionine mixed into the diet or small mammals collected at Kesterson (Yamamoto et al. 1998), and from captive screech-owls fed selenomethionine (Wiemeyer and Hoffman 1996). Results of the present study were consistent with captive studies and what we have learned about the amount of foraging on and off Kesterson. The geometric mean blood-Se for all avian predators sampled to date at Kesterson is slightly lower than the geometric mean selenium concentration of small mammals collected from Kesterson in 1994, 1995, 1996, and 1998 (7.1 ppm; whole body selenium [Table 2]).

TABLE 2

Total selenium concentrations (ppm, dry weight) in potential prey species of predatory birds at Kesterson. Analyses were for whole animals. Sample sizes (*n*), range of whole-body selenium concentration (Range), and geometric mean selenium concentrations (GM) are shown.

Species	1994 – 1996			1998		
	<i>n</i>	Range	GM	<i>n</i>	Range	GM
Invertebrates			10			14
Beetle	167	0.60 - 41	13	64	4.2 – 61	17
Cricket	34	2.3 - 26	7.8	4	3.9 – 24	12
Grasshopper	107	1.3 - 22	5.8	34	1.8 – 17	7.3
Spider	79	4.5 - 48	14	35	8.1 – 36	17
Mammal			6.0			7.1
Deer mouse	71	1.3 - 131	6.8	30	2.0 – 19	6.7
Western harvest mouse	19	4.0 - 15	7.9	17	2.4 – 20	7.7
House mouse	31	2.2 - 22	8.3	31	0.71 – 35	7.9
Ornate shrew	1		18	1		7.5
California vole	79	0.32 - 26	5.3	7	0.63 – 16	4.4
Desert cottontail	27	0.23 - 11	3.6			
California hare	15	0.4 - 18.9	4.3			
California ground squirrel	19	2.1 - 44	7.1			

Note: Small mammal samples were collected from Kesterson in 1994, 1995, 1996, and 1998. Invertebrate samples were collected only in 1994, 1995; and 1998 no invertebrate samples were collected in 1996. No small mammals or invertebrates were collected in 1997.

In captive kestrel studies, a log-linear relationship was observed between selenium concentration in the diet and blood selenium concentrations (Yamamoto et al. 1998). This relationship is described by the equation:

$$\log \text{ blood-Se} = 0.34 + 0.552 (\log \text{ diet-Se})$$

Based on this equation, expected blood-Se from avian predators feeding only on small mammals at Kesterson would be 6.5 ppm (5.0 – 6.9 ppm), somewhat (26 percent) higher than the mean observed for kestrels (4.8 ppm) or all avian predators (i.e., 5.2 ppm). Using a more complex food chain model based on Kesterson monitoring data and field and laboratory studies, kestrels at Kesterson in 1998 (feeding 60 percent on-site) would have an average blood-Se of 4.1 ppm and egg-Se of 4.5 ppm (actual 1998 kestrel egg-Se was 3.4 ppm). The accumulation of selenium in the blood of kestrels from dietary sources (an approximately 1:1 relationship) is less than that reported in mallards, in which blood-Se plateaued at about 3 to 4 times the experimental dietary concentrations of 10 and 20 ppm (Heinz and Fitzgerald 1993). Comparisons of blood-Se to dietary concentrations could not be made for avian predators in other study areas, because sampling and analysis of diet species was only conducted at Kesterson. However, given that selenium accumulation in birds has typically been studied using relatively high dietary exposures, such information would be useful in determining whether accumulation is similar at lower dietary selenium concentrations.

Although generally lower than at Kesterson, few of the birds sampled in the other study areas had blood-Se concentrations at or below the typical “background” concentration of about 2 ppm (see Table 1). Geometric mean blood-Se of species in other study areas was highly variable, with ranges in individual birds from background to concentrations comparable to those at Kesterson (1.0 – 16 ppm). The highest off-site blood-Se was in a shrike sampled about 7 km west of Kesterson. The highest blood-Se from an off-site kestrel was 7.3 ppm in a sample collected in the Sacramento Valley about 120km NNW of Kesterson (near the city of Rio Vista). These data may be largely explained either by the location of the study areas in agricultural landscapes of the Central Valley (where irrigation practices in some areas may concentrate selenium in water and, potentially, in wildlife food-chains), or by recent migration from affected areas.

Selenium-related wildlife problems have been identified in other regions of the San Joaquin Valley and elsewhere, though reported effects have been limited to aquatic habitats and species. In the Tulare Lake Basin severe reproductive impairment was documented in aquatic birds utilizing irrigation water evaporation ponds that contained average selenium concentrations of up to 1.0 ppm (NIWQP 1998). Similarly, evidence of reduced reproductive success has been found for black-necked stilts nesting at the Salton Sea, where average selenium concentration in water was about 1.5 ppb (Westcot 1990). Blood-Se of kestrels we sampled near the Salton Sea was slightly above background (GM = 2.5 ppm) and did not indicate exposure to toxic dietary selenium concentrations. Whether and to what degree selenium from irrigation drainage water is a potential hazard for terrestrial wildlife species remains poorly understood. At Salton Sea, seleniferous drainwater predominantly occurs in canals and the Sea, possibly limiting exposure by avian terrestrial predators, whereas, the Kesterson Area pastures and duck clubs have historically received seleniferous agricultural drainage water (Presser and Barnes 1985). Seleniferous drainwater is not known to occur in the Sacramento Valley, though levels in birds are still above background (Table 1).

Interestingly, mean blood-Se in shrikes from the Kesterson Area was approximately equal to or higher than that of shrikes and other species from Kesterson. Shrikes in the Kesterson Area, where agricultural drainwater was historically used for marsh management (Ohlendorf et al. 1987), may have been exposed to elevated levels of dietary selenium. It is possible that shrikes trapped in the Kesterson Area were also foraging at Kesterson, though not likely given the distance the birds would have been required to travel (up to 16km). Alternatively, 6 of the 8 shrikes were trapped in November ($n = 1$), January ($n = 3$), or February ($n = 2$) and may have dispersed from Kesterson a short time before sampling. More data on selenium residues in shrikes and shrike dietary habits are required in both study areas to better characterize these exceptionally high selenium levels, and to identify probable sources.

Comparison of Blood-Se of Species at Kesterson

Among species at Kesterson, shrikes had significantly higher blood-Se than kestrels, barn owls, and red-tailed hawks, and harriers had higher blood-Se than barn owls and red-tailed hawks (Table 3). General factors contributing to species differences in blood-Se probably include relative time spent foraging at Kesterson, which is influenced by both seasonal movements and home range characteristics; dietary composition (various dietary items contain differing concentrations of selenium [see Table 2]); and species-specific differences in selenium metabolism. Both loggerhead shrikes and northern harriers nest at Kesterson. Based on previously reported home ranges (Preston 1990) and on observations of these species at Kesterson, the highest blood-Se levels observed in shrikes and harriers are probably due in large part to these birds spending relatively more time than other species foraging at Kesterson. Shrikes maintain relatively small home ranges (about 8.5 ha in California; Miller 1931) and generally are not migratory, suggesting that individuals trapped at Kesterson spend a large portion of their time within this area. Similarly, because samples were obtained primarily from breeding harriers at Kesterson, blood-Se data reflect individuals foraging for extended periods of time primarily at this site. Harriers in particular may be able to utilize interior portions of Kesterson to a greater extent than some other raptors, due to their preferred hunting method of low coursing over foraging terrain. There are no trees and few artificial structures in the interior areas of Kesterson, and predatory birds that rely primarily on perch-hunting (such as red-tailed hawks, kestrels, and owls) tend to forage on the periphery of Kesterson where power poles and fence posts offer ample perching sites. For these species, this behavior most likely results in varying degrees of foraging outside of Kesterson, thus moderating selenium intake from prey items at Kesterson.

An exposure model developed for Kesterson in 1993 predicted dietary selenium after 10 years (2002) of 6.8 ppm for red-tailed hawks and 8.5 ppm for northern harriers (Ohlendorf and Santolo 1994, Santolo 1994). In general, findings from the present study agree with the model prediction for harriers, but were below predicted values for red-tailed hawks (see Table 1). This is likely due to a significant proportion of samples being collected from migratory or dispersing hawks that were transient at Kesterson and feeding offsite to varying degrees. In the future, more focused monitoring of blood-Se in resident red-tailed hawks at Kesterson would further aid in verification of model predictions from the 1993 risk assessment.

TABLE 3

Summary of Se Concentrations (ppm dry weight) in Predatory Birds Collected from Kesterson, 1994 – 1998

Species	n	Range	Geometric Mean ^a
American kestrel	94	1.5 – 28	4.8 B
Red-tailed hawk	44	2.1 – 8.7	3.9 B
Northern harrier	6	6.3 – 15	9.4 A
Barn owl	115	1.5 – 12	4.3 B
Other owls	3	6.1 – 11	8.7 A,B
Loggerhead shrike	29	4.9 – 38	12 A
All	298	1.5 – 38	5.0

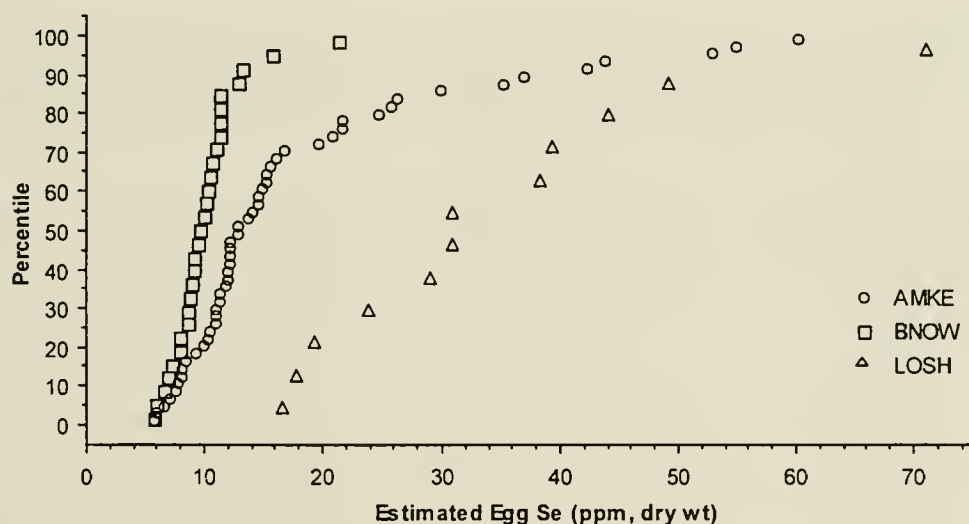
^a Within species, GM not sharing the same letter are significantly different ($P \leq 0.05$).

Calculated Concentrations of Selenium in Eggs

Calculated egg-Se values, based on blood-Se data from Kesterson birds captured during the spring (i.e., March through June) and a blood-to-egg selenium equation developed in captive kestrels, are shown in Figure 1 for three species. These calculations indicate that 77 percent of kestrel eggs, 100 percent of shrike eggs, and 48 percent of barn owl eggs would exceed a previously suggested threshold for avian reproductive impairment of 10 ppm based on mallards (Heinz 1996).

FIGURE 1

Predicted Egg Selenium in American kestrels (AMKE) Barn Owls (BNOW) and Loggerhead Shrikes (LOSH)



In contrast, eggs collected from kestrel nest boxes at Kesterson in 1997 – 1998 did not exceed the threshold, and had significantly lower selenium concentrations than egg-Se calculated from female parent blood-Se (Table 4). Similarly, measured geometric mean selenium concentrations in barn owl (GM = 4.0, range = 2.4 – 8.0, $n = 6$) and shrike (GM = 5.3, range = 4.5 – 6.0, $n = 4$) eggs were lower than the corresponding calculated values of 9.7 ppm (range 5.7 – 21, $n = 29$) for barn owls and 31 ppm (range = 17 – 71, $n = 12$) for shrikes (no differences in measured egg-Se were observed among kestrels, barn owls, and shrikes, $F_{2,18}$; $P = 0.154$). Therefore, calculated egg-Se values were conservative with respect to prediction of reproductive hazards to the birds. The discrepancy between calculated and observed egg-Se suggests the possibility that selenomethionine does not closely simulate naturally incorporated selenium with respect to maternal transfer to eggs of these species. Another source of error may be the timing of blood sampling of wild parent birds. Most adults were captured after egg-laying to avoid causing abandonment of the nest or handling females carrying eggs. Therefore, most samples from breeding adults were not obtained until after egg-laying, with some collected after hatching. Whereas the blood-to-egg selenium equation assumes a pre-laying exposure period that results in near steady state concentration of selenium, at Kesterson exposure is probably highly variable. Many seasonally resident birds are probably not exposed to elevated dietary selenium prior to arriving at Kesterson. Once arriving at Kesterson, they may be exposed to highly variable dietary selenium levels and may still have relatively low body burdens of selenium at the time of egg-laying. Since the removal of aquatic habitat in 1988, routine biological monitoring as well as a European starling (*Sturnus vulgaris*) nest-box study conducted in 1995, have revealed no evidence of reproductive effects in terrestrial birds at Kesterson, though data on nesting raptors are few. It is anticipated that kestrel nest-box studies now in progress at Kesterson will provide more definitive information on whether current selenium concentrations pose a threat to reproduction of terrestrial birds.

TABLE 4

Female parent blood (Blood-Se) during nesting and egg selenium (Egg-Se) concentrations (ppm, dry weight) of American kestrels collected from nest boxes at Kesterson during 1997 and 1998. Egg selenium concentrations calculated from parent blood selenium and the ratio of observed-to-calculated egg selenium are shown for comparison.

Nest box	Year	Blood-Se	Egg-Se		Ratio Observed:Calculated
			Observed	Calculated ^a	
01 – 02	1997	11.6	4.0	24.7	6.2
01 – 02	1998	17.2	3.1	35.3	11.4
01 – 04	1997	3.0	3.1	7.3	2.4
01 – 04	1998	6.4	2.9	14.5	5.0
04 – 05	1998	9.6	4.8	20.9	4.4
08 – 01	1997	4.7	3.7	11	3.0
12 – 02	1998	27	5.0	52.9	10.6
12 – 04	1998	3.5	2.3	8.4	8.4

^a Only female blood selenium was used for predicting egg selenium concentrations.

Comparison of Blood-Se in Re-trapped Adult Birds

Ten birds were sampled more than once at Kesterson during the course of this study (Table 5). Within individuals, blood-Se was observed to decrease, increase, or remain stable between initial and subsequent samples. No consistent trend or seasonal differences were found in this limited data set. Six kestrels were sampled twice within a month during the nesting period, and all but one exhibited variable increases in blood-Se by the second sample time. Large variations in blood-Se within individuals are probably attributable to changes in prey selection and availability over time, as well as a high degree of temporal and spatial fluctuation in soil selenium affecting bioavailability (Wahl et al. 1994), and therefore prey concentrations, at Kesterson (see Table 2). In addition, because dietary selenium is relatively quickly absorbed into the blood, blood-Se measurements are especially sensitive to recent exposure levels. Most re-sampled birds were birds nesting (i.e., either year-round or seasonally resident) on Kesterson and foraging over 40 percent in areas adjacent to Kesterson where selenium concentrations were assumed to be at reference levels (see Nest Box and Telemetry Study). Blood-Se was generally consistent with the presumed resident status of re-sampled birds, in that most samples were at least twice background in selenium concentration (NIWQP 1998).

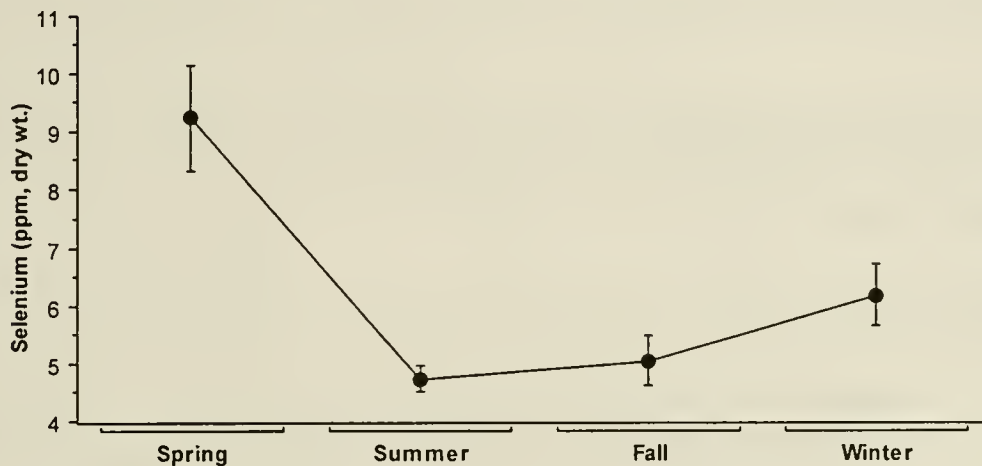
TABLE 5

Blood-Se (Se) and date of sampling (Date) in American kestrels, barn owls, and loggerhead shrikes from Kesterson sampled more than once.

ID	Initial		1 Month		< 1yr		1yr+		2yr	
	Date	Se	Se	Date	Se	Date	Se	Date	Se	Date
<i>American kestrel</i>										
220	29 Mar 97	2.7					2.6	20 Dec 98		
231	17 May 97	5.1			12.4	18 Apr 98	14.3	2 May 98		
240	7 Jun 97	11.6			6.4	5 Apr 98	4.7	9 May 98		
251	2 Nov 97	6.8			6.8	25 Apr 98	31.1	30 May 98		
252	2 Nov 97	5.7			2.9	25 Apr 98				
271	5 Apr 98	9.6	17.2	9 May 98						
274	5 Apr 98	10.0	12.1	19 Apr 98	2.2	20 Dec 98				
275	18 Apr 98	4.9	5.3	9 May 98						
<i>Barn owl</i>										
584	11 Nov 94	6.1					3.6	30 May 98		
503	4 Jul 95	5.1					4.9	18 May 96	3.8	10 May 97
<i>Loggerhead shrike</i>										
812	7 Jun 97	20.0					11.0	28 Jun 98		

Birds sampled in the spring (February through June), during the nesting season, had significantly higher selenium concentrations than those trapped in summer, when birds are dispersing from their natal territories, (July through September) and during migration in the fall (October through December; Figure 2). Spring samples were not significantly higher than samples collected in the winter. Spring and winter are the seasons that birds may be resident at Kesterson (i.e., breeding and wintering seasons) and this may partly explain why higher blood-Se concentrations are found during these seasons. However, there is a great deal of variability because some individual kestrels, barn owls, and shrikes have been observed at Kesterson during all seasons and are probably year-round residents.

FIGURE 2
Seasonal Blood-Se in Birds from Kesterson, 1994 – 1998



Predatory birds at Kesterson exhibited variable but consistently elevated selenium concentrations in their blood, relative to birds sampled in other areas of California. Based on these findings, and on previous studies with captive kestrels (Yamamoto et al. 1998), blood-Se appears to be a useful indicator of minimum dietary selenium exposure in predatory, and potentially other, terrestrial birds. Calculated egg concentrations, based on blood samples taken during the breeding season, suggest risk of reproductive effects for individuals that nest at Kesterson. Although such effects have not been documented in the course of biological monitoring at Kesterson, continued focused observations and sampling, particularly in resident and breeding raptors and shrikes, are warranted. Comparative data will continue to help characterize species differences in exposure to selenium and associated risks, and identify critical determinants of selenium bioaccumulation in these birds.

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9. Nest Box and Telemetry Study

Introduction

To date, adverse reproductive effects in terrestrial birds have not been observed in the course of avian monitoring at Kesterson. To better study selenium exposure patterns of terrestrial birds, artificial nest boxes were placed on and around Kesterson during the late winter-early spring period in 1996 to attract American kestrels (*Falco sparverius*), a target monitoring species at Kesterson. Under these circumstances individual birds and their nests can be monitored closely to provide site-specific information on exposure to, and the effects of, high dietary selenium concentrations. In 1997, initial data on selenium tissue concentrations, diet, reproductive success, and foraging range were collected on five successful kestrel nests (three on Kesterson, two off-site). In 1996, European starlings (*Sturnus vulgaris*) also occupied the nest-boxes and were sampled extensively for selenium in tissues and for dietary composition analysis (see CH2M HILL 1996). Nest-box studies have been used by others (e.g., Grue and Christian 1981, Craft and Craft 1996) to study effects of contaminants on avian reproductive success.

In addition to the kestrel/starling nest boxes, four barn owl (*Tyto alba*) nest boxes were placed in the southern ponds at Kesterson during 1996-1998. Selenium residue and reproductive success data have been collected on nesting owls since 1996. Barn owls are common all year at Kesterson, and are capable of breeding year-round when conditions permit (Marti 1992).

In 1998, nest-box studies were continued with kestrels and barn owls. In addition, a second year of foraging range information was collected for nesting kestrels. Data for barn owls and kestrels are described in this section; starling data are reported in Section 7 (Bird Nesting and Reproduction).

Methods

Setting Up the Nest Boxes

On February 7 through 9, 1996, 30 kestrel nest boxes were set up on Kesterson. They were placed in lines running east-west, approximately 1/4 mile apart (Figure 1). Eleven of the boxes were fastened to existing power poles within Kesterson (eight nest boxes were located along the San Luis Drain and three along Gun Club Road) and 19 were fastened to 12ft pressure-treated 4 × 4s sunk about 3ft into the ground. At each of these locations the posts were placed on the highest point in the area to gain additional elevation. Wood shavings were added to each box to line the bottom with at least three inches of shavings. Each box was given a unique code. Codes identified type of nest (NB), where the box was located (Pond 1 through 12 or State Route 140 or 165) and a series beginning with the number 1 for each pond. For example NB01-01 identifies a nest box in the northeast corner of Pond 1 and NB 01-04 identifies a nest box in the southwest corner of Pond 1. Aluminum tags with the

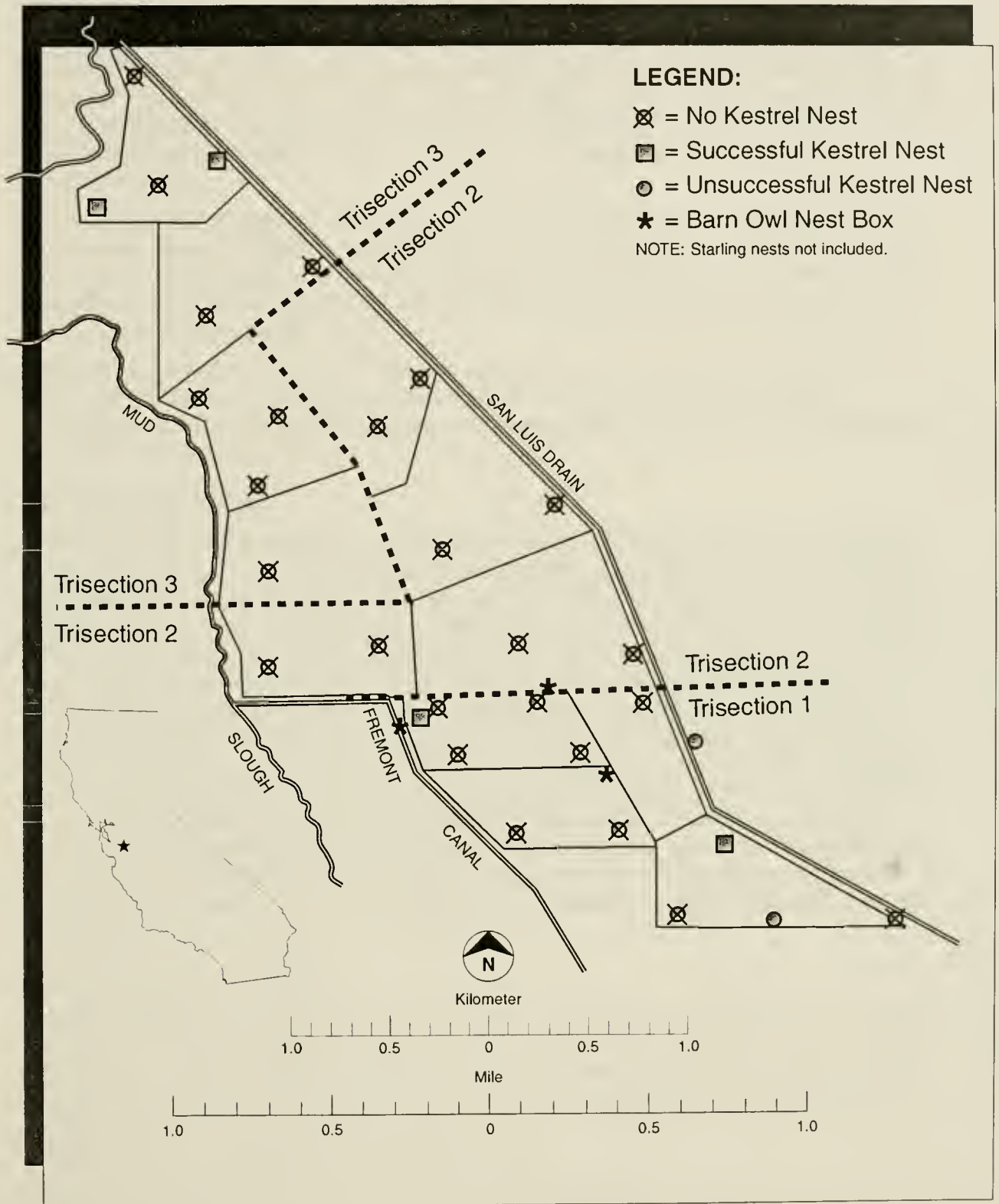


Figure 1
Approximate Locations and Fate of Nests
and Nest Boxes on Kesterson, 1998

number were attached to each nest pole and the location and number were identified on a map.

On March 1, one more box was fastened to an existing pole in the northwest corner of Pond 4 (Trisection 1). Five boxes were also installed outside Kesterson: two along Highway 140 by the main entrance to Kesterson National Wildlife Refuge (KNWR), and three on Highway 165 from the east gate of KNWR (i.e., the intersection of Highway 165 and the San Luis Drain) south. Four of these were mounted on existing poles and one was attached to a eucalyptus tree.

The nest boxes were made of redwood, about 1-1/2ft tall, 1ft deep, and 1ft wide. The lids were either hinged or totally removable with hook and eye clasps to lock them on. Boxes were ventilated through the entrance hole and through holes drilled in the bottom. Prior to nesting seasons in 1997 and 1998, nest boxes were inspected for damage, cleaned out and refilled with pine shavings.

Barn owl boxes were set up in 1996 (compound adjacent to Pond 4), 1997 (Ponds 3 and 5), and early 1998 (Pond 1). Nest boxes were made of wood or plastic, with varying construction designs, and were hung on 4 × 4 posts or already available structures at heights of 6 to 8ft above the ground.

Nest Box Monitoring

Pairs of kestrels and barn owls were observed for signs of nesting beginning in March of 1998. Established kestrel pairs were identified by observations of birds entering and leaving nest-boxes, nest territory defense behavior, and food deliveries by the male to the female at the box. Barn owl nests were identified primarily by observation of eggs in the nest boxes. Nest boxes were checked at several times during the reproductive period: during egg-laying or early incubation when one egg was collected for viability assessment and selenium analysis; during chick rearing, when chicks were assessed for overall health/normality, banded (Federal bands), and blood-sampled; and during post-fledging, when fledging success was determined (absence of chicks or chick remains in or near the box was assumed to indicate successful fledging). Capture of the adult female in the nest box was attempted during early incubation, after egg-laying was complete; females were blood-sampled, banded (Federal bands), and placed back in the nest box within approximately 30 minutes of capture. Nest boxes that were apparently occupied by kestrels, but then abandoned, were also checked to assess stage of reproduction at which abandonment occurred and fate of the adult kestrels.

Radiotelemetry Data Collection

After establishment of the nest and during the incubation phase of reproduction, attempts were made to trap the males of these pairs using dho-gaza or bal-chatri trapping methods (Bub 1991). Trapped birds were banded with a Federal band, and blood-sampled. Prior to release, transmitters weighing approximately 2g with 5-month battery life (Holohill, Inc., Canada) were attached to tail feathers using small metal clasps, glue, and cotton thread. Radiotagged birds were released at the capture site.

Radiotagged birds were tracked by car and foot approximately three days per week, using a hand-held yagi antenna, and an ICOM (Model IC H-16) receiver. Attempts to locate individual birds were made at approximately 2-hour intervals throughout each tracking day

between the hours of 0600 and 1800. Locations were visual (with binoculars) if possible, but were estimated using triangulation when necessary. Observers in cars maintained a distance of about 1/4 mile from birds to minimize the influence of observers on bird movement. Each radiotagged bird was tracked from the time of capture until the signal ceased (transmitter failure or dispersal of bird away from the monitoring area) or fledging of kestrel chicks, whichever occurred sooner.

Each time a bird was located, its position was noted on a map and denoted with an identifying number, which corresponded to data for that observation on a separate data sheet. In addition to location, other variables were recorded: time, whether observation was visual or auditory (triangulation), whether the bird was perched or flying, perch type (wire, pole, tree, etc.), activity (hunting, social interactions), and weather conditions at the time of the observation. All activities were recorded for five minutes after locating a bird. Changes in position during this period were recorded as "activities" and not as location data. Location data were transformed into latitude-longitude in the field using a hand-held global positioning unit.

Results

Reproductive Success

Six nest boxes on Kesterson (20 percent occupancy) and two off-site boxes (40 percent occupancy) were used by American kestrels during the breeding season. Kesterson nests were located on the edge of the Kesterson in Ponds 1, 2, 4, and 12 (Figure 1). There were two off-site nests located north of Kesterson: one was near the entrance to the KNWR and the other was located at the south end of the refuge.

Four of the six nests on Kesterson (Ponds 1, 4 and 12) and one of the two off-site nests successfully fledged young (Table 1). No developmental abnormalities were observed in kestrel chicks or in embryos of collected eggs from Kesterson or off-site nests. All three of the kestrel nesting failures (on and off Kesterson) were attributed to the disappearance of the female adult during egg-laying or incubation. In neither case was loss of the adult bird believed to be selenium-related.

TABLE 1
Reproduction in kestrels and barn owls using nest boxes on and off Kesterson Reservoir, 1998

Species	Nest Location	Number of Nests	Mean Clutch Size	% Incubated Eggs Hatched	% Developmental Abnormalities	% Successful Nests
Kestrel	Kesterson	6	5	100	0	67
Kestrel	Off-site	2	6	100	0	50
Barn owl	Kesterson	4	4	89	0	50

Three barn owl nest boxes were utilized on Kesterson in 1998; two were interior locations (Ponds 3 and 5) and one was located in the compound off of Gun Club Road on the west side of Kesterson (Figure 1). Both of the interior nest boxes successfully fledged chicks,

whereas the nest box in the compound failed during two nesting attempts. Both failures occurred during incubation, once due to depredation of the eggs and once due to disappearance of the female adult. Two of four barn owl chicks in the Pond 5 nest box were found dead in the nest box at about 6 weeks of age (the other two chicks fledged successfully from this nest box). Based on examination of the remains, depredation did not appear to have been the cause of death; however, the carcasses were too badly decomposed to make a detailed diagnosis. No developmental abnormalities were observed in barn owl chicks or in embryos of collected eggs.

Selenium Concentrations

Selenium concentrations in blood and eggs of kestrels that nested on Kesterson were similar to those from off-site nests (Table 2). Mean blood selenium in adult kestrels from Kesterson was slightly lower than that of offsite adults, but higher maximum concentrations were observed in onsite individuals (e.g., Ponds 1, 4, and 12). Egg and blood samples from some nest boxes (sibling chicks from the same clutch pooled) approached previously suggested "background" concentrations (i.e., about 2 ppm; Heinz 1996). In on-site nests, selenium in adult or juvenile blood showed greater variability than eggs, and for all nests, selenium concentration tended to be higher in blood than in eggs.

TABLE 2
Selenium Concentrations (ppm dry weight) in Kestrel and Barn Owl Blood and Eggs, 1998

Species	Nest Location	Egg Se			Adult Blood Se			Chick Blood Se ^a		
		<i>n</i>	Range	GM	<i>n</i>	Range	GM	<i>n</i>	Range	GM
Kestrel	Kesterson	4	2.3 – 5.0	3.4	9	2.4-27	8.1	4	2.7-28	6.1
Kestrel	Off-site	2	2.2-3.5	2.8	3	7.5-10	9.1	1		5.6
Barn owl	Kesterson	4	2.4-6.7	3.4	3	3.6-5.6	4.4	3	3.5-8.1	4.8

^aData shown for two weeks of age in kestrels, and three weeks of age in barn owls.

In comparison with kestrels, data for barn owls breeding at Kesterson reflect similar selenium concentrations in eggs, and somewhat lower concentrations in adult and nestling blood. Among barn owl nests, adult blood, juvenile blood and eggs had similar mean selenium concentrations and ranges. Multiple blood sampling of owl and kestrel chicks at weekly intervals after hatch indicate no consistent pattern of increase or decrease over time (Table 3), with barn owls exhibiting a high degree of stability over time with respect to selenium in the blood.

TABLE 3
Blood-Se in kestrels and barn owls using nest boxes on and off Kesterson Reservoir, 1998

Chick ID	Egg-Se	Blood-Se						
		Parent ^a	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
NB 01-04	2.3	6.4						
87284			3.1	2.3				
87285			4.2					
87286			3.9					
87287			3.4	5.3				
NB 04-05	4.8	9.6						
87288				28.1				
87289			6	21.9				
87290			4.9					
NB12-02	5.0	27						
87291			6.6	5.3				
87292			6.8	7.2				
87293			9.0	6.4				
NB165-01	3.5	10						
87279			4.4					
87280			5.6	5.6				
87281			5.2	5.2				
87282			4.7					
87283				6.2				
BO 03-01a	2.4	5.6						
39578			4.7	4.2	4.2			
39579			3.8	4.0	4.0			
39580			3.7	3.7	3.7			
BO 03-01b	No egg	7.9						
39581			9.4	9.2	9.3	11	9.1	
39582			6.2	7.2	7.4	7.4		7.0
39583			8.1	7.6	7.6	6.7		
39584			10	8.1	8.4	7.9		8.8
BO 05-01a	2.8	4.3						
39573				4.1	3.3			
39574			2.3	3.3	3			
39575			2.4	7.0	5.8			
39576			2.8	4.4	2.7			

^a Parent blood-Se is the earliest sample taken during nesting.

Radiotelemetry Data

Breeding male kestrels from four nest boxes in 1997 (Ponds 1, 4, 8, and off-site box 165-01) and three in 1998 (Ponds 1, 4, and 12) were successfully radiotagged (Table 4). Additionally in 1998, a breeding female in off-site box 165-01 was also radiotagged, but she removed the transmitter before sufficient data (for foraging range analysis) were collected.

Radiotelemetry observations in 1997 indicated that breeding male kestrels on Kesterson foraged about 58 percent of the time on-site, and moved from 1.3 to 3.4 km from the nest box during foraging bouts.

In 1998, based on preliminary analyses of telemetry data, male kestrels were observed about 53 percent of the time on Kesterson. Males at nestboxes NB 01-02 and NB 01-04 (ID #'s 3 and 11) were observed less often on-site than males from nestboxes NB 04-05 and NB 12-02 (ID #'s 4 and 7). Observations were extremely limited for the male in Pond 12, however, due to premature loss of his transmitter. Causes of termination of observations of other radiotagged birds were as follows: male # 3 abandoned his territory and dispersed away from Kesterson after his nest failed due to predation during late incubation; male # 4 was apparently killed, based on his sudden disappearance from the area, during the early nestling period; male # 11 was tracked during nestling, fledging, and post-fledging periods before his transmitter failed.

TABLE 4

Telemetry Observations of American Kestrels at Kesterson, 1997 and 1998

Nest Location	Bird ID	# Days Observed	# Total Observations	% Observations on Kesterson ^a	Maximum Foraging Distance (km) ^b	Termination of Observations
Kesterson						
Pond 1-02	3	10	72	32		abandoned
Pond 1-04	11	36	193	10		transmitter failure
Pond 4	4	17	115	77		bird died?
Pond 12	7	11	14	92		removed transmitter
Mean				53		
Offsite						
Highway 165	6	3	7	-	-	removed transmitter

^a Based on preliminary counts of data; values are subject to changes with future analyses.

^b Maximum distances have not been calculated yet.

Discussion

Among kestrel pairs that successfully laid eggs in this study, hatchability and fledging success were high in Kesterson and in off-site areas. Adult kestrel mortality was responsible for two early nesting failures on Kesterson. Because selenium levels in kestrels at Kesterson (5.4 ppm) are not in range to cause adult mortality (10 - 15 ppm dietary exposure [NIWQP

1998]), mortality was not believed to be directly attributable to selenium exposure. Similarly, the barn owl nest sampled resulted in 3 out of 4 remaining eggs (after one was collected) hatching and fledging successfully. The success of this nest was similar or higher than that of barn owls in southern California (P. Bloom, Western Foundation of Vertebrate Zoology, personal communication) and other barn owl populations (Marti 1992). No developmental abnormalities were found among Kesterson and off-site nests, which is in agreement with previous nest monitoring data for other terrestrial species at Kesterson. These results are also consistent with the relatively low selenium concentrations found in the collected eggs, all of which were below a suggested avian threshold for reproductive impairment of 10 ppm (Heinz 1996).

Occupancy of nest boxes by kestrels was lower than expected. Potential limiting factors for increased occupancy include habitat quality, intraspecific food competition, interspecific nest box competition (commonly observed at Kesterson between kestrels and starlings), and disturbance (construction on the San Luis Drain may have caused the abandonment of a nest box in Pond 12 in 1996). Maximum foraging distances of kestrels, based on radiotelemetry observations, are consistent with previously reported home range information for kestrels (Balgooyen 1976, Rudolph 1982). Based on the results of other studies (Bechard and Bechard 1996), it is expected that in 1999 there will be at least the same, and possibly a greater, number of kestrel pairs using nest boxes on and off Kesterson.

The similarly elevated blood selenium concentrations in Kesterson and off-site kestrels was not surprising, given the close proximity of two of the off-site boxes to the Grasslands State Park. This refuge is known to have relatively high environmental levels of selenium, due to releases of agricultural drainage water onto the refuge. It is likely that one or both members of these two off-site pairs foraged at least partially on the refuge. In future seasons, efforts will be made to locate nest boxes in uncontaminated areas near Kesterson, in order to provide more useful reference data. On average, blood selenium concentrations in both groups of nesting birds were similar to the overall mean for nonbreeding kestrels trapped from 1994-1997 on Kesterson (6.4 ppm, dry weight). These concentrations are below that observed in kestrels fed a dietary Lowest Observed Adverse Effect Level (LOAEL) of 12 ppm selenium, and are not expected to be associated with adverse effects in wild kestrels (Santolo et al. 1999). Compared with other predatory bird species sampled at Kesterson, kestrels tend to be similar in selenium accumulation to red-tailed hawks, but lower than barn owls, northern harriers, and loggerhead shrikes. These species differences are probably in large part due to differences both in relative amount of time spent foraging at Kesterson and on prey species selection.

Selenium concentrations in eggs of kestrels at Kesterson were less than blood selenium concentrations of parent birds; this was unexpected, based on data from captive kestrels indicating an approximate blood-to-egg transfer factor range of 1.7-2.8. Given the variability inherent in the blood selenium concentrations of wild birds, it is unlikely that this relationship can be verified in the field with opportunistic, single blood samples (from parent birds) that are not closely timed with egg-laying. Compared with other bird species sampled at Kesterson in past years, kestrels in 1998 exhibited relatively lower selenium accumulation in eggs (mean for all bird eggs sampled 1989-1998 = 5.5 ppm selenium, dry weight). For the barn owl nest box, ratio of blood-to-egg (about 2) was similar to the expected ratio for kestrels.

Based on pellet and nest box content analyses, the dietary compositions of barn owl and kestrel diets from Kesterson are fairly typical for these species (Knight and Jackman 1984, Marti 1987, Yalden and Morris 1990, Balgooyen 1976, Rudolph 1980, Collopy and Koplin 1983). Invertebrates, which have previously been found to predominate in breeding kestrel diets in California, contribute almost twice as much selenium to the kestrel diet as do vertebrate dietary items. Assuming an approximate 1:1 relationship between blood and dietary selenium concentrations (determined in captive kestrel studies; Yamamoto et al. 1998), and about 60 percent foraging on-site (indicated by preliminary telemetry data this year), the estimated dietary concentration of 8 ppm selenium for kestrels breeding at Kesterson would predict about 4.8 ppm in the blood. That this predicted concentration is equivalent to the mean concentration of selenium in the blood measured in these kestrels indicates that the captive kestrel model of selenium accumulation may be useful for predicting wild bird exposures.

If the 1:1 ratio (diet: blood) is also assumed for barn owls, the close agreement between the blood (3.8 ppm) and diet (4.4 ppm) selenium concentrations of the single female barn owl sampled suggest that this individual forages primarily on Kesterson, in spite of the nest being located on the reservoir edge. This bird had previously been trapped on Kesterson and banded on July 4, 1995, north of the compound nest location. At that time, the selenium concentration in her blood was 5.1 ppm. In 1996, selenium concentrations were the same in both this adult and one of her chicks (4.9 ppm). Blood selenium levels across years in this individual suggest stability of both foraging range and selenium concentrations in dietary items. The latter has been observed during the course of biological monitoring of small mammals over this period at Kesterson.

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10. Small Mammals

Introduction

Although adverse effects of dietary selenium have been observed in both livestock (NRC 1980) and laboratory mammals (Halverson et al. 1966, Schroeder and Mitchner 1971), these effects have not been observed in free-living mammals at Kesterson (Clark 1987, Clark et al. 1989, Ohlendorf and Santolo 1994).

As part of ongoing post-remediation monitoring at Kesterson, small mammals were trapped and analyzed for total selenium. Species targeted for collection were deer mice (*Peromyscus maniculatus*), western harvest mice (*Reithrodontomys megalotis*), house mice (*Mus musculus*), and California voles (*Microtus californicus*), which are all common rodents in California and occupy a range of habitats, often sympatrically. They are of similar size and all (except California voles which are herbivorous) are considered to have generalized diets. Other coexisting species collected at Kesterson included here are Heermann's kangaroo rat (*Dipodomys heermanni*) and ornate shrews (*Sorex ornatus*). These species have more specialized diets (i.e., granivorous and insectivorous, respectively) and occupy a narrower range of habitats.

Objectives

The objectives of monitoring small mammals at Kesterson were to (1) verify the observations of Clark (1987); (2) identify adverse selenium effects occurring over time if, they exist; (3) monitor the effects of management on small mammals at Kesterson; and (4) to characterize the potential selenium exposure to predatory birds through their prey base at Kesterson.

Methods

Trapping

Trapping was typically conducted from February through June, except in 1998 when rainwater pools covered Kesterson into June and trapping was continued into August. Small mammals were trapped in upland areas of Kesterson in 1987 and 1988 and over the entire Kesterson site from 1989 through 1995 (only limited trapping was conducted during 1996) and in 1998. In 1987, mammal trapping was conducted by U.S. Fish and Wildlife Service personnel for the Kesterson Program; these data are only used for selenium comparisons. After 1987, Museum Special snap traps (Woodstream, Pennsylvania) and Sherman live traps (H. B. Sherman Traps, Tallahassee, Florida) were baited with peanut butter and wild birdseed and placed in suitable areas of available habitat and areas with signs of small mammal activity. Traps were set at dusk and checked each morning, baited again, and reset, as necessary. Snap traps were used until about 30 individuals of a species were captured

(10 per trisection) and then live traps were used. After the target number was reached for a species, additional live-trapped individuals of that species were usually released.

Reproductive Status and Age Classification

The reproductive status and age were determined for most animals collected from 1988 – 1998. The determination of reproductive activity of males was made by observing testis size and condition of the cauda epididymis. Determination of reproductive activity in females was made by observing the presence or absence of embryos and placental scars and mammary gland condition (Christian 1950, Conaway 1955). Ages of small mammals were estimated by examining pelage coloration, total body length, mass, and reproductive condition (Conaway 1955).

Measurements

Animals were weighed to the nearest 0.1g, and total body (head-tail) and tail lengths were measured to the nearest 1mm and recorded. For each animal, the stomach was opened lengthwise, beginning at the pylorus, and the contents were removed and stored in a container with an approximately equal amount of table salt and then kept frozen until examined.

Selenium Analysis

Small mammals collected in 1987, 1988, 1992, 1993, 1995, and 1996 were analyzed as whole animals, liver and carcass were analyzed separately (whole body was calculated) for mammals from 1989 through 1991, and in 1994 and 1998 only liver was analyzed (whole body selenium was estimated from a regression equation based on 1989 – 1991 liver:carcass selenium concentrations [Ohlendorf and Santolo 1994, Santolo 1994]). Samples were stored at -20° C, then shipped to a commercial laboratory (Environmental Trace Substances Research Center, Columbia, Missouri) from 1987 to 1991. After 1991, samples were shipped to Laboratory and Environmental Testing, Columbia, Missouri) on dry ice for total selenium analysis.

Results

Mammals Captured

Percent success for mammal trapping was lowest in 1993 (2.8 percent) and highest in 1991 (20 percent, Table 1). Over the ten years of trapping, 57 percent of the small mammals sexed were males and in only two years (1993 and 1998) were more females than males captured. In 1984, Clark (1987) also captured higher numbers of males than females at both Kesterson and the Volta Wildlife Management Area, a reference site.

In 1995, 3 percent and in 1998, 32 percent of the small mammals sexed appeared to have both male and female reproductive tracts (intersexes). In 1995, 2 of the 17 house mice and 1 of the 11 western harvest mice were possibly intersex mice. In 1998, 2 of 7 (29 percent) voles, 15 of 33 (46 percent) house mice, 7 of 30 (23 percent) deer mice, and 5 of 17 (29 percent) harvest mice were possibly intersex mice. There was no perforation of the skin in the vaginal area and externally these animals appeared to be males.

TABLE 1

Success and sex ratio of small mammals (California voles, deer mice, western harvest mice, house mice, Heermann's kangaroo rats, and ornate shrews) captured at Kesterson from 1988 to 1998.

Year	<i>n</i> ^a	Trap nights	Success (%)	<i>n</i> ^b	Male/Female
1988	246	1,451	17.0	64	33/31
1989	176	3,744	4.7	147	90/57
1990	301	1,501	20.1	105	59/46
1991	210	1,291	16.3	193	112/81
1992	89	740	12.0	72	42/30
1993	60	2,143	2.8	59	29/30
1994	348	2,243	15.5	92	62/30
1995	163	1,350	12.0	105	58/44 ^c
1996	53	350	15.1	27	12/15
1998	93	743	12.6	87	18/40 ^c
1988-1995	1,739	15,556	11.2	951	518/404

^a Number of small mammals captured.

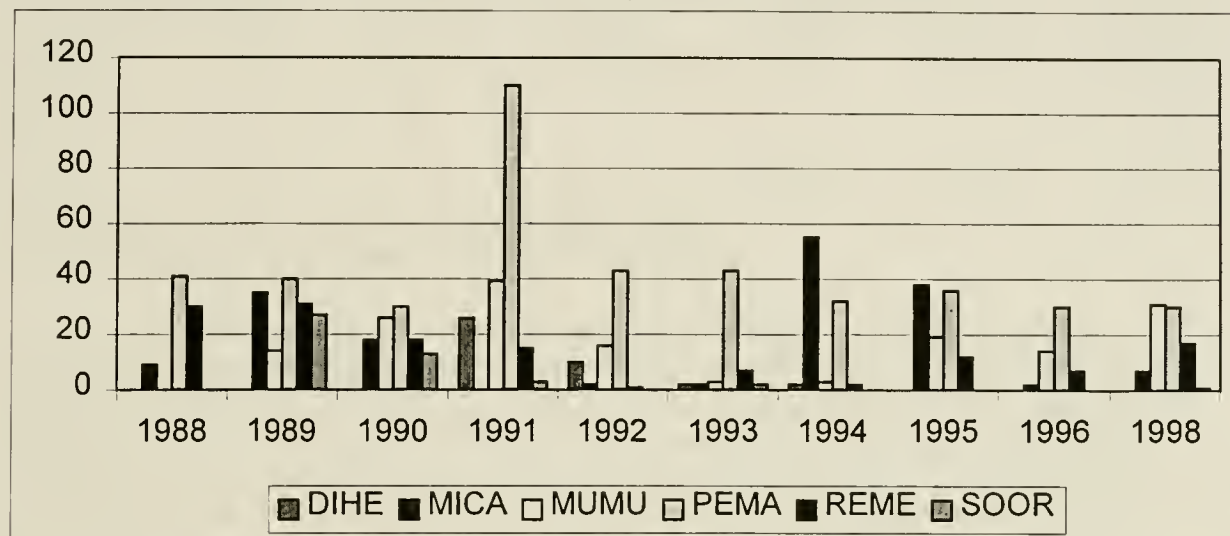
^b Number of small mammals sexed.

^c In 1995, 3 and in 1998, 27 small mammals had both male and female reproductive tracts.

From 1988 to 1998, deer mice accounted for 40 percent of the total captures, California voles for 18 percent, house mice for 17 percent, western harvest mice for 16 percent, ornate shrews for 5 percent, and Heermann's kangaroo rats 4 percent. Deer mice were the only species that were consistently abundant during each of the 11 years. The number of voles captured was relatively high in 1989; fewer were trapped in 1990, no voles were captured in 1991, and only 2 in each of the next 2 years before becoming abundant again in 1994. Western harvest mice were relatively abundant in 1988 and 1989 and were found in lower numbers in subsequent years. The number of house mouse trapped increased from 1989 to 1991 and then decreased until 1995, when higher numbers were captured. Shrew captures decreased from 1989, and no shrews were captured in 1992, 1994, and 1995. Heermann's kangaroo rats were not observed at Kesterson until 1991. Since then, the number of captures have decreased, and kangaroo rats have rarely been observed on the site since 1994 (Figure 1). This was after heavy spring rain in 1993 flooded the low-lying areas where their burrows were located.

FIGURE 1

Number of Heermann's kangaroo rats (DIHE), California voles (MICA), house mice (MUMU), deer mice (PEMA), western harvest mice (REME), and ornate shrews (SOOR) trapped each year at Kesterson from 1988 to 1998.



Measurements

Body weights of mice captured at Kesterson were similar to published (Silva and Downing 1995) averages (Table 2). The average weight of voles was slightly lower but within the range reported for California voles. Similarly, body length ([total body length - tail length] from Ingles 1965) was slightly smaller in Kesterson-trapped deer mice, harvest mice and California voles but the averages fell within the normal ranges for these species in California. Body lengths for house mice and California voles were slightly larger than those reported by Clark (1987) from Volta Wildlife Management Area. House mice captured at Kesterson in 1984 were smaller but voles were the same as those captured from 1988 to 1998.

TABLE 2

Body weight (g), total length (mm) condition index (CI, [g body weight/mm body length³]), and selenium concentration (ppm, dry wt) in adult small mammals collected, weighed, and measured at Kesterson from 1988 to 1998.

	Deer Mouse	Harvest Mouse	House Mouse	California Vole	Kangaroo Rat	Ornate Shrew
Weight^b						
$\bar{x}$	19.6	10.2	16.3	44.6	75.2	4.5
<i>n</i>	262	108	88	110	24	42
Range	11.0 - 48.2	7.3 - 15.2	8.4 - 25.1	19.0 - 76.5	67.0 - 87.3	2.2 - 5.9
Body length^b						
$\bar{x}$	87.9	69.5	82.5	117.9	123.5	62.5
<i>n</i>	256	107	82	107	22	39
Range	69 - 130	50 - 81	66 - 138	95 - 150	115 - 129	47 - 70
Body condition Index^b						
$\bar{x}$	0.22	0.15	0.19	0.38	0.61	0.073
<i>n</i>	255	107	82	106	22	39
Range	0.14 - 0.58	0.11 - 0.21	0.086 - 0.33	0.20 - 0.58	0.56 - 0.69	0.046 - 9.8

TABLE 2

Body weight (g), total length (mm) condition index (CI, [g body weight/mm body length^a]), and selenium concentration (ppm, dry wt) in adult small mammals collected, weighed, and measured at Kesterson from 1988 to 1998.

	Deer Mouse	Harvest Mouse	House Mouse	California Vole	Kangaroo Rat	Ornate Shrew
Selenium						
GM	7.5	6.1	7.6	7.8	4.7	21
<i>n</i>	246	115	81	106	20	42
Range	1.3 – 137	1.5 – 38	0.71 – 31	0.33 – 66	1.0 – 27	7.4 – 125

^a Body length is total length (tip of nose to tip of tail) minus tail length.

^b Intersex individuals not used for weight, length, and condition index.

To determine if mass or size was affected by significantly higher whole-body selenium concentrations, small mammals were separated into three groups based on significantly different selenium concentrations and compared. These selenium groups were designated as Background (< 1.0 to 4.0 ppm, NIWQP 1998), Elevated-Se (4.1 to 10.0 ppm), and High-Se (> 10.0 ppm). House mice and deer mice from both the Elevated- and High-Se groups were significantly larger (i.e., both weight and body lengths were significantly greater) than those from the Background group. However, only in house mice was the body condition index significantly higher in the Elevated- and High-Se groups over background mice. There were no other significant differences found in weight, length (total length minus tail length), or condition index between the Elevated- or High-Se mammals and any other groups.

Selenium Concentrations

1998 Selenium Concentrations in Small Mammals

Selenium concentrations in small mammals collected in 1998 ranged from 4.4 ppm in voles to 7.9 in house mice but they were not significantly different among species (Table 3).

TABLE 3

Summary of Se Concentrations (ppm dry weight) in whole-bodies^a of Small Mammals Collected from Kesterson, 1998

Species	<i>n</i>	Geometric Mean ^b	Range
Ornate shrew	1	7.5	
Deer mouse	30	6.7	2.0 – 19
Western harvest mouse	17	7.7	2.4 – 20
California vole	7	4.4	0.63 – 16
House mouse	31	7.9	0.71 – 35
All small mammals	86	7.1	0.63 – 35

^a Whole-body selenium for intersexes collected in 1998 were estimated using the equation from Santolo (1994): $\log \text{ whole-body Se} = -0.378 + 1.0925 (\log \text{ liver-Se})$.

^b There was no significant difference in Se concentrations among species in 1998 ($n \geq 3$, Tukey-Kramer HSD $P \leq 0.05$).

Small mammals were compared by the habitat type that they were trapped in (Table 4). Even though small mammals trapped in Open habitat had slightly higher selenium concentrations than those trapped in Grassland or Filled habitats, there was no significant difference in small mammal selenium among habitats. There was no difference in selenium concentrations in small mammals collected from Trisections 1 and 2, but selenium concentrations in small mammals trapped in Trisection 1 and Trisection 2 were higher than those collected in Trisection 3 (Table 4).

TABLE 4

Summary of Se Concentrations (ppm dry weight) in Whole-bodies^a of Small Mammals Collected from Kesterson, 1998

Species	<i>n</i>	Geometric Mean ^b	Range
Habitats			
Filled	28	6.8	0.71 – 20
Grassland	10	5.3	2.4 – 16
Open	18	10	0.63 – 35
Trisections			
1	32	9.2 A	0.63 – 35
2	32	7.9 A	2.4 – 19
3	22	4.1 B	1.9 – 19

^a Whole-body selenium for intersexes collected in 1998 were estimated using the equation from Santolo 1994): $\log \text{ whole-body Se} = -0.378 + 1.0925 (\log \text{ liver-Se})$.

^b There was no significant difference in small mammal Se concentrations among habitats in 1998; within Trisections, small mammal Se concentrations not sharing the same uppercase letter are significantly different (Tukey-Kramer HSD $P \leq 0.05$).

Intersex Small Mammals

In 1998, up to 29 of 87 small mammals examined may have been intersexes. This is a conservative estimate of occurrence because until the female reproductive structures become enlarged, identification as intersex is difficult and some individuals may have been incorrectly identified. The identification of intersexes is based on necropsy of individuals with structures that appear to be testes, uterus, and ovaries. There were no significant differences in selenium concentrations, capture location (within Kesterson), or habitat among the sexes. Most (23) intersexes were adults and the rest were aged as subadults; no juvenile intersexes were found. Based on external characteristics, 14 were identified as males in reproductive condition (testes were scrotal). Liver weight as a percent of body weight was significantly higher in intersexes than both males and females. Intersex deer mice and house mice had larger (left) testes than males, and intersex harvest mouse and vole testes were larger but not significantly larger than in males (harvest mice, $P = 0.086$; voles, $P = 0.083$).

Selenium Concentrations in Small Mammals Over Time

Ornate Shrew

Ornate shrews have shown consistently high geometric mean selenium concentrations (Table 5). Unlike deer mice, western harvest mice, and house mice that include invertebrates in their diets (sometimes in relatively high proportions) along with seeds and vegetation, shrews are primarily insectivorous. Shrews have become less common (based on trapping success) since 1987 and 1989 when they were trapped in relatively high numbers at Kesterson.

TABLE 5
Se Concentrations (ppm dry weight) in Ornate Shrews (whole body) Collected from Kesterson

Year	n	Range	Geometric Mean ^a	Comments
1984	2	10 – 100	32	From Clark (1987)
1987	29	8.7 – 58	25 A	Prior to dewatering and filling of Kesterson
1989	27	9.3 – 125	21 A	First sampling post filling of Kesterson
1990	13	7.4 – 44	19 A	
1991	2	14 – 17	15	
1993	2	34 – 43	38	Heavy March rain
1998	1		7.5	Ephemeral pools late into the summer

^a There was no significant difference in Se concentrations among years ($n \geq 3$, Tukey-Kramer HSD $P \leq 0.05$).

Deer Mouse

Selenium concentrations in deer mice have varied from year-to-year since 1989, the first sampling period after Kesterson was dewatered and filled (Table 6). Deer mice are the only small mammals that have been consistently abundant (based on trapping success) in all years since 1987. Food habit studies conducted from 1989 to 1993 showed deer mice to vary their diet, presumably based on availability: over the five years they were sampled (150 stomachs examined) they ate mostly seeds (41 percent), non-grass vegetation (35 percent), and invertebrates (20 percent). Small amounts of grass and mushrooms (about 2 percent of each) were also consumed.

TABLE 6
Se Concentrations (ppm dry weight) in Deer Mice (whole body^a) Collected from Kesterson

Year	n	Range	Geometric Mean ^b	Comments
1987	36	1.0 – 34	5.7 ABD	Prior to dewatering and filling of Kesterson
1988	36	1.5 – 97	9.9 BCE	Kesterson filled in fall of 1988.
1989	40	1.1 – 15	4.8 A	First sampling post filling of Kesterson
1990	29	2.6 – 13	6.3 AC	
1991	47	1.5 – 29	6.2 ADE	
1992	43	5.6 – 33	11 C	

TABLE 6

Se Concentrations (ppm dry weight) in Deer Mice (whole body^a) Collected from Kesterson

Year	n	Range	Geometric Mean ^b	Comments
1993	42	3.6 – 32	9.7 CD	Heavy March rain
1994	29	2.0 – 137	7.8 AC	
1995	36	1.3 – 38	6.3 ADE	
1996	10	2.0 – 13	5.4 AC	
1998	30	2.0 – 19	6.7 AC	Ephemeral pools late into the summer

^a Whole-body selenium for some individuals were estimated using the equation from Santolo 1994): $\log \text{whole-body Se} = -0.378 + 1.0925 (\log \text{liver-Se})$.

^b Geometric mean Se concentrations not sharing the same uppercase letter are significantly different ($n \geq 3$, Tukey-Kramer HSD $P \leq 0.05$).

Western Harvest Mouse

Selenium concentrations in western harvest mice have varied from year-to-year but during 1998 were similar to concentrations in deer mice (Table 7). However, the number of harvest mice available to sample decreased after 1989 and remained low until 1998 when they were once again captured in numbers equivalent to deer mice. Diet studies from 1989 to 1993 showed a great deal of overlap between harvest mice (47 stomachs examined) and deer mice but harvest mice ate slightly less non-grass vegetation (22 percent) and more seeds (51 percent), grass (3 percent), and invertebrates (24 percent). Only a trace amount of mushroom was found in the stomach contents in 1989.

TABLE 7

Se Concentrations (ppm dry weight) in Western Harvest Mice (whole body^a) Collected from Kesterson

Year	n	Range	Geometric Mean ^b	Comments
1984	5	2.4 – 27	8.9 AB	From Clark (1987)
1987	24	0.60 – 13	4.1 AC	Prior to dewatering and filling of Kesterson
1988	30	1.5 – 38	5.0 AB	Kesterson filled in fall of 1988.
1989	31	2.7 – 29	6.3 AB	First sampling post filling of Kesterson
1990	18	2.1 – 18	6.5 AB	
1991	15	1.1 – 15	3.5 A	
1992	1	19	19	
1993	7	5.2 – 13	8.4 AB	Heavy March rain
1994	2	3.5 – 6.7	4.8	
1995	12	4.2 – 15	8.8 B	
1996	6	4.2 – 22	8.5 AB	
1998	30	2.0 – 19	6.7 BC	Ephemeral pools late into the summer

^a Whole-body selenium for some individuals were estimated using the equation from Santolo 1994): $\log \text{whole-body Se} = -0.378 + 1.0925 (\log \text{liver-Se})$.

^b Geometric mean Se concentrations not sharing the same uppercase letter are significantly different ($n \geq 3$, Tukey-Kramer HSD $P \leq 0.05$).

House Mouse

House mouse captures decreased from 1991 rates and, as in harvest mice, were not trapped in high numbers again until 1998. Selenium concentrations in house mice collected in 1992 and 1993 were slightly (but not significantly) higher than those captured in 1998 (Table 8). Other than 1992 and 1993, whole body selenium concentrations, as in the other mice sampled, remained relatively stable since 1988 when Kesterson was filled. House mouse diets (81 stomachs examined) overlap with deer mouse diets and especially with harvest mouse diets. Like harvest mice, they ate more seeds (51 percent) and invertebrates (23 percent) and less non-grass vegetation (22 percent). They ate slightly more grass (5 percent) than either deer mice or harvest mice and like harvest mice only had a small amount of mushroom in their overall diet in 1991.

TABLE 8

Se Concentrations (ppm dry weight) in House Mice (whole body^a) Collected from Kesterson

Year	n	Range	Geometric Mean ^b	Comments
1984	5	3.4 – 44	13 AC	From Clark (1987)
1989	14	2.2 – 9.7	4.1 B	First sampling post filling of Kesterson
1990	23	1.7 – 24	7.2 BC	
1991	28	4.3 – 20	9.6 AC	
1992	16	7.4 – 31	14 A	
1993	3	7.2 – 15	11 AB	Heavy March rain
1994	3	6.9 – 18	9.5 AB	
1995	19	2.2 – 13	7.4 AB	
1996	9	3.9 – 19	8.5 AB	
1998	31	0.70 – 35	7.9 A	Ephemeral pools late into the summer

^a Whole-body selenium for some individuals were estimated using the equation from Santolo 1994): $\log \text{ whole-body Se} = -0.378 + 1.0925 (\log \text{ liver-Se})$.

^b Geometric mean Se concentrations not sharing the same uppercase letter are significantly different ($n \geq 3$, Tukey-Kramer HSD $P \leq 0.05$).

California Vole

California vole selenium concentrations and abundance (based on trapping success) have shown a high degree of variability over the years they have been sampled (Table 9). Selenium concentrations in voles have also varied greatly among years. Vole populations are known to cycle (Krebs 1966) and this may account for the annual differences observed in vole numbers at Kesterson. The contents from 55 stomachs examined from 1989 to 1993 contained primarily vegetation (54 percent non-grass and 37 percent grass). Seeds (1 percent), mushroom (0.03 percent), and invertebrates (2 percent) are probably ingested inadvertently while foraging on vegetation.

TABLE 9

Se Concentrations (ppm dry weight) in California Voles (whole body^a) Collected from Kesterson

Year	<i>n</i>	Range	Geometric Mean ^b	Comments
1984	4	1.4 – 33	7.3 AB	From Clark (1987)
1987	12	14 – 64	32 B	Prior to dewatering and filling of Kesterson
1988	9	3.2 – 15	8.1 AC	Kesterson filled in fall of 1988
1989	34	1.0 – 81	14 BC	First sampling post filling of Kesterson
1990	18	2.9 – 79	9.3 AC	
1992	2	1.6 – 32	2.3	
1993	2	3.8 – 8.7	5.8	Heavy March rain
1994	51	0.33 – 28	6.0 A	
1995	38	1.4 – 19	4.5 A	
1996	2	5.5 – 10	7.4	
1998	7	0.60 – 16	4.4 AC	Ephemeral pools late into the summer

^a Whole-body selenium for some individuals were estimated using the equation from Santolo (1994): $\log \text{whole-body Se} = -0.378 + 1.0925 (\log \text{liver-Se})$.

^b Geometric mean Se concentrations not sharing the same uppercase letter are significantly different ($n \geq 3$, Tukey-Kramer HSD $P \leq 0.05$).

Spatial and Temporal Selenium Concentrations in Small Mammals

Selenium concentrations at Kesterson show a gradient of decreasing concentration in biota from south to north. This gradient was also observed in the small mammals sampled during 1989 – 1998. The geometric mean selenium concentration in small mammals collected from Trisection 1 was significantly higher than that in small mammals from Trisection 2, and means of small mammals from both Trisections 1 and 2 were significantly higher than the geometric mean of those from Trisection 3 (Table 10).

TABLE 10

Summary of Se Concentrations (ppm dry weight^a) in Small Mammals Collected from Kesterson, 1989 – 1998^b

Species	<i>n</i>	Geometric Mean ^c	Range
1	329	11 A	0.63 – 137
2	305	6.9 B	0.33 – 81
3	237	5.2 C	0.33 – 33
Kesterson	871	7.5	0.33 – 137

^a Whole-body selenium for some individuals were estimated using the equation from Santolo (1994): $\log \text{whole-body Se} = -0.378 + 1.0925 (\log \text{liver-Se})$.

^b 1989 – 1998 shown to reflect the post-remediation small mammal selenium concentrations.

^c Within Trisections, small mammal Se concentrations not sharing the same uppercase letter are significantly different ($n \geq 3$, Tukey-Kramer HSD $P \leq 0.05$).

Although conditions at Kesterson and selenium concentrations in much of the biota were different prior to dewatering and filling of Kesterson in 1988, selenium concentrations in small mammals remained fairly constant. There is high variability of selenium concentrations both within and among years. Mean selenium concentrations have remained elevated over background (i.e., > 4 ppm) without any clear long-term trend toward higher or lower concentrations. Whole body selenium concentrations were slightly higher in 1992 and 1993 but they were significantly higher than the other means only in 1995 (Table 11).

TABLE 11

Se Concentrations (ppm dry weight) in Small Mammals (whole body^a) Collected from Kesterson

Year	n	Range	Geometric Mean ^b	Comments
1984	16	1.4 – 100	11 A	From Clark (1984)
1987	101	0.60 – 64	9.9 A	Prior to dewatering and filling of Kesterson
1988	75	1.5 – 97	7.4 A,B	Kesterson filled in fall of 1988
1989	146	1.0 – 125	8.4 A,B	First sampling post filling of Kesterson
1990	101	1.7 – 79	8.1 A,B	
1991	114	1.0 – 29	6.1 B	
1992	72	1.6 – 33	10 A	
1993	58	3.6 – 43	10 A	Heavy March rain
1994	85	0.33 – 137	6.6 A,B	
1995	105	1.3 – 38	5.9 B	
1996	27	2.0 – 22	7.1 A,B	
1998	86	0.60 – 35	7.1 A,B	Ephemeral pools late into the summer

^a Whole-body selenium for some individuals were estimated using the equation from Santolo (1994): $\log \text{whole-body Se} = -0.378 + 1.0925 (\log \text{liver-Se})$.

^b Geometric mean Se concentrations not sharing the same uppercase letter are significantly different ($n \geq 3$, Tukey-Kramer HSD $P \leq 0.05$).

Discussion

Selenium concentrations in small mammals collected from Kesterson in 1998, as in other years, are above the < 1 – 4 ppm range suggested as background in mammals (NIWQP 1998). No adverse effects known to be associated with selenium toxicity were observed in mammals collected from 1987 – 1998, in agreement with 1984 findings of Clark (1987). Fluctuations in small mammal populations observed over this time can be attributed to climatic changes (i.e., the drought from 1988 to 1994, regional flooding in 1997, and the El Niño weather pattern in 1998), changes in plant species composition and structure due to succession, and other such factors of natural variation. Various measurements (i.e., body weight, length, condition) were not correlated with selenium concentration and were comparable to published “normal” measurements.

A significant finding in small mammals collected in 1998, assuming that the identification was correct, was a high frequency of possible intersex individuals across four species. Three of the 105 small mammals collected in 1995 also showed this abnormality. We have not been able to find this abnormality described in the literature, nor have we found other biologists who have observed this phenomenon in a wild population. However, in few other areas have small mammals been monitored as intensively as they have been monitored at Kesterson. Identification of these animals as intersexes is, as of yet, based solely on gross necropsy and professional opinion. At this time the identification of these individuals as intersexes seems to be the most plausible explanation based on the small amount of information available.

Sexual differentiation in mammals occurs early in development. Early in fetal life, both the male and female reproductive system has an undifferentiated gonad that is indistinguishable between the sexes. The "default" sex in mammals is female. Male sexual development depends on the Y chromosome testis-determining factor (SRY) which is involved with the secretion of Müllerian-duct inhibiting substance (MIS) from the Sertoli cell. MIS causes the Müllerian duct (i.e., the female reproductive structures) to regress. For normal male development, testosterone, produced by the Leydig cells in the testes is required. This type of abnormality would most likely be caused by exposure of the stressor(s) to the maternal parent during early embryonic development.

The cause of this abnormality is unknown. Laboratory studies of primate, hamster, rat, and mouse reproduction using various forms of selenium have not shown this effect. However, exposure to the agent that caused the formation of intersex offspring probably would be to the female parent prior to or during pregnancy. Similar abnormalities have been produced by causing genetic mutations in laboratory mice (Aaronson 1998, Vainio et al. 1999, Parr and McMahon 1998). However, mutations in these experiments are not restricted to the reproductive tracts as they are in the mice found at Kesterson. If the intersex abnormality was seen across four species it is unlikely that it is the result of a genetic mutation and it is probably the result of environmental influences. It seems more likely that some environmental agent is disrupting early embryonic development and tissue differentiation via exposure of adult females. However, Kesterson is a fairly 'closed system'; it no longer receives drainwater, there is no insecticide or herbicide application within the site, and there are no other obvious contaminant sources within the area. Thus, naturally occurring agents should also be considered as having a role in this phenomenon. It is also unknown whether this is a more widespread phenomenon that was only found at Kesterson because of the intensive biological monitoring conducted there. This phenomenon may be more widespread. As a result of the observations made at Kesterson, other rodents trapped in 1998 were also examined for the occurrence of intersexes. Preliminary results of trapping along the coast in Orange County during November 1998 found as many as 6 percent of 95 rodents collected were identified as intersexes (G. Santolo, unpublished data). These animals were not in reproductive condition and more study needs to be done to confirm this observation.

Although no selenium effects have been found in small mammals, data collected on these species provide information on selenium in the food chain and the exposure to predatory species of concern. The apparent high frequency of intersex mammals found at Kesterson in 1998 suggests the presence of an environmental stressor(s) and warrants further study. First,

the identification of these as intersexes needs to be verified by histology of the reproductive organs. Fundamental questions that should be addressed are:

- What are possible conditions at Kesterson that could be the cause of this effect?
- What is the genetic sex of these animals?
- Are the gonads functional (either the testes or ovaries)?
- Is this a wide spread phenomenon?
- What is the frequency of occurrence?
- Does it occur in other species (e.g., predators)?
- What effect does this have on small mammal populations?
- Is there a potential for secondary exposure to small mammal predators?
- What are the human health implications?

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10.	Small Mammals.....	10-1
	Introduction	10-1
	Objectives	10-1
	Methods.....	10-1
	Trapping.....	10-1
	Results.....	10-2
	Mammals Captured.....	10-2
	Measurements	10-4
	Selenium Concentrations	10-5
	Selenium Concentrations in Small Mammals Over Time	10-7
	Spatial and Temporal Selenium Concentrations in Small Mammals...	10-10
	Discussion	10-11
	References	10-13

Appendix A



IN REPLY REFER TO:

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Sacramento Fish and Wildlife Office
3310 El Camino Avenue, Suite 130
Sacramento, California 95821-6340

January 29, 1999

Gary Santolo
CH2M HILL

Subject: Kesterson Biomonitoring Program

Dear Gary:

As a follow-up to our meeting yesterday I am transmitting to you some analyses I have conducted on the avian egg data from the 1998 Kesterson Biomonitoring Program.

This letter does not address, explicitly or implicitly, any policy issues or Fish & Wildlife Service policy positions. The purpose of this letter is solely to provide technical assistance regarding avian risk assessment - - as you continue to prepare a final annual report for the 1998 Kesterson Biomonitoring Program.

As I had mentioned to you earlier, the stilt response curve for Se-induced teratogenesis reported in Skorupa (1998) is continually being updated with new data. The curve reported in Skorupa (1998) was based on 611 data points. The first thing I did with your 1998 Kesterson data was to compare your results for stilts against my latest update of the stilt response curve based on 791 data points.

Analysis #1 (Black-necked Stilts; teratogenesis): I focused first on the 7 stilt eggs you collected and immediately processed in 1998 that were estimated to be ≥ 7 days into incubation (BNST P01-02; BNST P01-05a; BNST P01-05b; BNST P04-01; BNST P04-04; BNST P04-05; BNST P05-02) and therefore were advanced enough to be fully assessable for overt terata. Based on the selenium results for those 7 eggs and the latest stilt logistic response curve, I generated predicted probabilities of teratogenesis for each egg and compared the sum of the predictions against actual observations.

Applying the logistic response equation leads to the prediction that 0.064 out of the 7 embryos (or 0.9%) would be teratogenic (i.e. far less than 1; or alternatively that about one sample of 7 embryos out of every 20 samples of 7 would include a teratogenic embryo in it). Thus, the observed outcome of no teratogenic embryos is predicted to have about 19 chances out of 20 of being the observed outcome and therefore the actual observed outcome is in agreement with the existing logistic equation.

Analysis #2 (Black-necked Stilts; teratogenesis): Next I focused on the eggs that were collected and transferred to UC Davis for artificial incubation (AI). Whole-egg chemistry results are not yet available for those eggs, but a matched sibling egg from each of the same nests was collected and chemistry data are available for those eggs. For the sake of preliminary risk assessment, I made the assumption that the chemistry results for the matched sibling eggs will prove to be reasonable estimates of selenium exposure in the AI eggs and that the error inherent in such an assumption will be random (i.e., counterbalancing). Thus, predicted probabilities of teratogenesis can be generated for the 14 AI stilt eggs that produced assessable embryos (BNST P01-01; BNST P01-02; BNST P01-04; BNST P01-05a; BNST P02-01; BNST P03-02; BNST P03-03; BNST P04-01; BNST P04-02; BNST P04-03; BNST P04-04; BNST P04-05; BNST P05-02; BNST P12-01) .

Applying the logistic response equation leads to a prediction that 0.28 out of the 14 embryos (or 2%) would be teratogenic (or alternatively that about one sample of 14 embryos out of every 4 samples of 14 would include a teratogenic embryo in it). Thus, the observed outcome of no teratogenic embryos is predicted to have about 15 chances in 20 of being the observed outcome and once again the actual observed outcome is in agreement with the existing logistic equation.

Analysis #3 (Black-necked Stilts; teratogenesis): Because the above analyses suggest that the 1998 stilt data from Kesterson are perfectly consistent with the existing logistic response curve for teratogenesis, I added the 7 data points currently available for Kesterson from 1998 (see Analysis #1) to the master data set (now N = 798) and once again updated the logistic regression before generating final predictions for teratogenic risk at Kesterson for 1998.

I also pooled together all 21 stilt eggs that produced assessable embryos and their measured or estimated selenium exposures. Based on this sample of 21, the predicted probability of teratogenesis for stilts at Kesterson in 1998 is 1.62%. Although that predicted probability is about 8X above the directly measured background rate of 0.2% for stilts (in eggs containing ≤ 5 ppm Se) , it is still low enough in absolute terms that for a sample size of 21 there is only a 29% chance of detecting ≥ 1 teratogenic embryo.

You documented a total of 20 stilt nesting attempts at Kesterson in 1998. Assuming that each nest included 4 eggs, about 80 eggs were produced. Assuming that your chemistry results are representative (which they should be since nearly every nest was sampled), at a predicted 1.62% rate of teratogenesis about 1.3 (i.e., 1-2) teratogenic stilt embryos would have been expected for the entire nesting population.

The maximum selenium exposure of 42 ppm documented for a stilt egg in 1998 would be associated with about a 15% probability of teratogenesis.

Analysis #4 (Killdeer; teratogenesis): The killdeer logistic response master database for teratogenesis currently includes a sample of 96 data points. These data do not yet produce a logistic regression with sufficient precision to be applied directly to risk assessment for killdeer. What can be done, however, is to test the killdeer data against the precisely defined stilt curve to see if the killdeer data are at least consistent with the stilt curve, and if they are, the stilt curve can be used for assessing risk for killdeer.

Based on the 96 killdeer data points and the stilt logistic regression (N=798 version) a prediction can be generated that the killdeer data set should include 5.7 cases of teratogenic embryos and 90.3 cases of "normal" (not overtly multiply deformed) embryos. The observed ratio in the killdeer database is 2 teratogenic and 94 normal. This difference from predictions is not statistically significant, chi-square = 2.55, with one degree of freedom, and $p > 0.10$. Thus, there is no strong statistical evidence yet that would preclude applying the stilt logistic equation to risk assessments for killdeer. However, to the extent that the differences between predicted and observed ratios reported above are due to factors other than random sampling error (**if at all**), the preliminary indication is that killdeer might be less sensitive to embryonic selenium exposure than stilts. Thus, to the extent that a risk assessment for killdeer based on stilt equations might be in error, the error would probably be on the side of overestimating risk (i.e., on the side of safety).

Analysis #5 (Killdeer; teratogenesis): Following the same general methods, assumptions, and rationale of Analysis #'s 1-3 above, there are 25 killdeer eggs from the 1998 samples at Kesterson that provide assessable embryos for which a known or estimated selenium exposure is available (KILL 140-01; KILL P01-05; KILL P0-06; KILL P01-07; KILL P01-09; KILL P01-10; KILL P01-11; KILL P01-12; KILL P01-14; KILL P02-02; KILL P03-05; KILL P05-03; KILL P07-03; KILL P09-02; KILL P11-02 collected and AI; KILL P11-03; KILL P11-04; KILL P11-05 collected and AI; KILL P12-04; KILL P12-05 collected and AI; KILL P12-06 collected and AI).

Based on this sample of 25, the predicted probability of teratogenesis for killdeer at Kesterson in 1998 is 0.7%. Although that predicted probability is about 3-4X above the expected background rate of 0.2% (for eggs containing <5 ppm Se), it is low enough in absolute terms that at a sample size of 25 there is only a 16% chance of detecting ≥ 1 teratogenic embryo which is consistent with the absence of teratogenesis in the collected sample.

You documented a total of 52 killdeer nesting attempts at Kesterson in 1998. Assuming that each nest included 4 eggs, about 208 eggs were produced. Assuming that your chemistry results are representative (which they should be since nearly every nest was sampled), at a predicted 0.7% rate of teratogenesis about 1.5 (i.e., 1-2) teratogenic killdeer embryos would have been expected for the entire nesting population.

The maximum selenium exposure of 31 ppm documented for a killdeer egg in 1998 would be associated with about a 5% probability of teratogenesis.

Analysis #6 (Black-necked Stilt and Killdeer ; egg viability): As has been reported in several laboratory feeding trials with mallards (Heinz et al. 1987, 1989; Stanley et al. 1994, 1996) and field studies with waterfowl and shorebirds (Ohlendorf et al. 1986; Ohlendorf 1989; Skorupa 1998), teratogenesis is not as sensitive a risk endpoint as is egg viability (i.e., hatchability).

During our meeting yesterday you identified for me 3 stilt nests and 11 killdeer nests that were believed to have been incubated to full term in 1998 and from which egg chemistry results are available. You indicated that no Fail-To-Hatch (FTH) eggs were recovered from any of those 14 nests and that you didn't know what the odds were that FTH eggs would persist long enough for you to recover them, considering the high level of activity of nest predators at Kesterson. For the sake of preliminary risk analysis, I'm assuming that in fact there were no FTH eggs in those 14 nests.

Based on a logistic equation I have calculated for the clutch-wise probability of ≥ 1 inviable egg as a function of the selenium content of a sample egg from the clutch, a prediction can be generated that about 2 (2.01) of the 14 full-term clutches should have contained ≥ 1 FTH eggs. The difference between that prediction and the actual observation of 0 affected clutches is not statistically significant, chi-square = 2.33, one degree of freedom, $p > 0.10$.

Based upon all nests that chemistry data are available for it is predicted that 17.4% of the stilt nests should have contained ≥ 1 FTH egg(s) and 13.5% of the killdeer nests should have contained ≥ 1 FTH egg(s). Keep in mind that without any selenium effect at all, about 9% of stilt and killdeer nests would be expected to contain ≥ 1 FTH egg (due to natural rates of infertility and other natural causes of inviability or embryo death). At low levels elevated inviability such as these, it would be rare for a single nest to contain more than one inviable egg. Under such conditions, the predicted eggwise incidence of inviability can be estimated by simply dividing by 4 (clutch size) the predicted clutchwise incidence. Consequently, it can be estimated for stilts that their level of exposure to selenium at Kesterson in 1998 was sufficient to cause the eggwise incidence of inviability to increase from a normal background of about 2.2% to 4.3% and for killdeer from a normal background of about 2.2% to 3.4%. On an absolute basis, this suggests that the total embryotoxic impact on stilts would have been about 1.7 out of the 80 eggs produced by the population and the total embryotoxic impact on killdeer would have been about 2.5 of the 208 eggs produced by the population.

Based on the predicted eggwise rates of inviability for stilts and killdeer presented above, it can be predicted that 1.4 of the 37 stilt and killdeer eggs placed in incubators at UCD should have failed to develop normally. The actual observed incidence was 2 out of 37 which does not differ significantly from expectations ($p > 0.50$).

The highest selenium exposure in any stilt egg for 1998, 42 ppm, would be associated with a 44% clutchwise probability of inviability. One of two eggs sampled from the 42 ppm clutch was indeed reported as inviable. The fate of the remaining eggs from that clutch is unknown (due to nest predation?). The highest selenium exposure in any killdeer egg for 1998, 31 ppm, would be associated with a 32% clutchwise probability of inviability. One egg sampled from the 31 ppm clutch was viable. The fate of the remaining eggs from that clutch is unknown (due to nest

predation?).

SUMMARY:

The egg data for stilts and killdeer, the two most abundant breeding waterbirds at Kesterson in 1998, exhibited a level of selenium exposure sufficient to expect selenium-induced embryo toxicity, but at only a low incidence.

Given the low levels of adverse effects predicted from the measured levels of exposure, the sample sizes of assessed embryos had low power (29% and 16%) for detecting teratogenic effects. Essentially, about 3 eggs out of the approximately 288 available for sampling would have been predicted to contain selenium-induced deformed embryos. Given that level of rarity, and sample sizes of 21 to 25 assessed embryos, the absence of documented deformed embryos cannot reliably be equated to an actual absence of teratogenic effects.

The high-end egg, 42 ppm Se, was predicted to be associated with a 44% clutchwise chance of embryotoxicity and in fact 1 of 2 eggs assessed from that clutch was inviable.

The data for 1998 reflect a lower level of *in ovo* selenium exposure than the data for 1997 (see FWS comment letter dated January 30, 1998). Considering the steepness of response curves for Se-induced embryotoxicity (e.g., Lemly 1998; Skorupa 1998) and the 1998 circumstances that appear to be just slightly above toxic threshold points, the reduction in exposure between 1997 and 1998 would be expected to have had disproportionate effects for reducing adverse effects (i.e., a small or moderate reduction in exposure would have a disproportionately large impact on reducing adverse effects).

Gary, please feel free to contact me with any questions or comments regarding these analyses and conclusions.

With best regards,

Joseph P. Skorupa

Attachment: References Cited

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